

**NONMETALLIC
MINERALS**

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NONMETALLIC MINERALS

BY

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Consulting Engineer

AND

W. M. MYERS

SECOND EDITION

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NONMETALLIC MINERALS

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PREFACE TO THE SECOND EDITION

Since the first edition of this book appeared in 1925 the nonmetallic mineral industries have changed greatly in nearly all important aspects. Prior to 1925 many of these industries were not founded on firm engineering and technical bases. Engineers and technicians familiar with the field were very few, and their knowledge was limited usually to one or two minerals. Few schools or colleges offered a course of instruction in the technology of industrial minerals. In the intervening years most of these industries have taken advantage of progress in technology and equipment with the result that today they little resemble their condition in the 1920's.

Perhaps the greatest strides have been taken in the field of mineral beneficiation. In 1925 we did not have froth flotation of nonmetallic minerals, sink-and-float concentration, high-intensity magnetic separation, workable electrostatic separation, improved centrifugal air separation, the micronizer, nor the efficient wet centrifuge. These new working tools have changed completely our ideas of what constitutes commercial ores, thus vastly increasing our reserves and changing the geographical picture of production.

Entirely new uses for industrial minerals have been developed, such as the use of barite for oil-well drilling muds, the use of talc in ceramics, and the large-scale use of feldspar in glass.

The industrial development of new areas of the country, such as the Gulf Coast, Calif., and the Pacific Northwest, as well as such economic factors as constantly increasing freight rates, have changed the geographic pattern of markets.

New and improved equipment and techniques for examining and testing minerals and mineral products, such as the electron microscope, X-ray diffraction methods and quantitative spectroscopic methods, have enabled us better to understand the properties of minerals and tailor them to our use.

Rocks and minerals formerly of no commercial interest have come into production. Among these may be noted nepheline syenite, aplite, dumortierite, topaz, perlite, pinite, olivine, and numerous others.

All this means that the first edition of this book needed not just revision but entire rewriting. In many chapters hardly more than 5 or 10 per cent of the original material could be allowed to stand without change either in

PREFACE TO THE SECOND EDITION

emphasis or in major content. In addition, bibliographic reference material, in most cases, is today 10 to 20 times as voluminous as it was in 1925. In this edition the references listed at the end of most discussions are referred to by superior numbers in the text.

The task of rewriting this work seemed far too great for the original author to undertake alone. This new edition is due largely to the willingness of the coauthor to collaborate in its preparation and to assume an important share of the burden. W. M. Myers is a former colleague, a friend of long standing, and an associate in various nonmetallic mineral activities. This edition is a dual effort and the contribution of the individual authors cannot be separated.

Acknowledgment is made freely and gratefully to the host of scientific and technical workers who have taken time from their labors to publish the results of their research and progress in technology in the technical press.

RAYMOND B. LADOO

NEWTON, MASSACHUSETTS
January, 1951

PREFACE TO THE FIRST EDITION

For several years the author was engaged in special work on various nonmetallic minerals in the U.S. Bureau of Mines at Washington, D.C. During this period he was constantly in receipt of requests for information concerning these minerals. Such requests covered a wide range of details, but in general touched on such subjects as composition and properties of the minerals, methods of mining and preparation, market values, extent and nature of markets, specifications and tests, and uses.

In order better to answer such requests an outline containing the most common questions was prepared. Thereafter a systematic attempt was made to collect information covering this outline for every mineral of commercial interest. The sources of information used were varied and extensive. They included, among others, published and unpublished reports by the various governmental and state departments and bureaus; articles published in the technical literature of the United States and foreign countries; correspondence and conferences with producers, consumers, engineers, chemists, geologists, and ceramists; and personal observation made in the field. In fact, every available source of information known to the writer on any phase of this subject was more or less thoroughly combed.

In time a great mass of data was obtained and it was suggested by several people that an attempt be made to summarize and condense it for publication. This task was finally undertaken with some misgivings and in full realization of the difficulty of saying anything of much value on over a hundred different minerals within the scope of a single volume of moderate size. The result, after repeated prunings of the original manuscript, is embodied in the present work.

So far as the author knows no previous attempt has been made to cover the field of the technology of the nonmetallic minerals, at least of the scope and nature of this present work. G. P. Merrill's "Non-metallic Minerals" treated the subject largely from the geological and mineralogical standpoint, and was written before the introduction of modern methods. For example, the Frasch process for the mining of sulfur had not been developed. James A. Audley's "Silica and the Silicates" covers a part of this field, but it does not cover the whole subject systematically and emphasizes particularly ceramic materials and processes.

Little that is really new or original is contained in this book. It is

PREFACE TO THE FIRST EDITION

largely a compilation, more or less critical, of published or unpublished facts and opinions of others. There may be some justification, however, for this method of treatment since much of the information used comes from widely scattered and often inaccessible sources. No attempt has been made to give credit to all sources of data, for often a dozen references have been consulted in preparing a single paragraph. Perhaps the most important single source of data has been the various publications of the U.S. Geological Survey, from which nearly all the statistics of United States production of minerals have been obtained.

The author wishes to express his gratitude to Miss Vera Crockatt of the U.S. Bureau of Mines for her patient and painstaking work in the preparation of the manuscript and in verification of references.

Grateful acknowledgment is also due to my wife, Ethel Keniston Ladoo, for her able assistance throughout all the stages of the preparation of this work.

RAYMOND B. LADOO

NEW YORK, N.Y.
March, 1925

ACKNOWLEDGMENTS

Unless otherwise indicated all the statistical data contained in this volume were obtained from the publications of the U.S. Bureau of Mines of the Department of the Interior. Their annual publication *Minerals Yearbook*, a complete review of all mineral activity, represents a continuation of the studies initiated by the U.S. Geological Survey and first published as *Mineral Resources of the United States* in 1882. Publication on an annual basis was continued until 1924, when the responsibility for preparation was transferred to the U.S. Bureau of Mines. In 1932 the name of the publication was changed to *Minerals Yearbook*. This continuous and incomparable series of volumes supplies the most complete single source of information relative to the origin and growth of the mineral industries in this country and is an invaluable aid to the student of mineral statistics. The authors wish to acknowledge their indebtedness to this source of data so freely drawn upon.

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INTRODUCTION

For convenience in classification the mineral kingdom may be divided in three classes: the fuels, the metals, and the nonmetals. The minerals included in each of these classes possess certain properties in common. The fuels are of organic origin and are used largely to produce energy through combustion, a market in which they are all competitive. The metallic ores are the sources of the common and rare metals, elements that display many properties and relationships in common. The rest of the mineral list that cannot be properly classified in the above category falls in the third group, the nonmetals. The nonmetallic group is characterized by the heterogeneity of its composition, many members displaying little or no resemblance to others in geologic origin, composition, method of recovery, or service to society. They are characterized by the frequency with which physical properties become of controlling importance. The preparation of the mineral for the market may consist of little more than extraction and change in shape so that certain extraordinary physical properties may be made useful. The fibrous nature of asbestos, the insulating ability of mica, the high specific gravity of barite are examples of minerals possessing an outstanding physical property that has been made useful and developed commercially to become the basis of a substantial industry. A knowledge of the physical properties of nonmetallic minerals and their role in commercial utilization is therefore of primary importance to the producer or the investigator of potential markets for new ventures.*

Certain minerals play a dual role. Hematite, the principal ore of iron, is also employed as a red pigment. Chromite may be used as an ore of chromium or as a refractory or the source of chromium chemicals. Bauxite, the most important source of aluminum, is also useful for refractories, abrasives, and adsorbents. In these cases and others of a similar nature the classification of the mineral depends upon its use and not upon composition. Such minerals are discussed in the text to the extent that they participate in the nonmetallic field.

Adequate supplies of nonmetallic minerals are of basic importance in the maintenance of the construction, ceramic, fertilizer, and chemical industries. The rapid growth of these industries in the last 40 years has been made possible by the development of productive capacity of suitable material. The contribution of these industries to the support of American living standards and to the defense of the country itself has been demonstrated so emphatically that the insurance of raw materials for an indefinite future is of prime importance to the economic security of the nation.

In the composition of the book certain basic principles have been followed as far as possible. Uniformity has been preserved by use of a standard outline as

* LADOO, R. B., Before Opening That Nonmetallic Property, *Mining and Met.*, November, 1939, pp. 503-508.

INTRODUCTION

far as the subject permits. Where a mineral is of considerable general interest and the literature meager and scattered, it may be given more attention than its industrial importance warrants. More important subjects may be treated less fully since literature pertinent to them is abundant and easily obtained. Very little space has been devoted to such large and important subjects as clays, cements, and stone, because anything like adequate treatment would require more space than can be given here and because satisfactory detailed information is obtainable elsewhere. Data concerning production in foreign countries have been introduced when particularly enlightening or when foreign sources are of special significance to American industry.

Under Physical and Chemical Properties the hardness of minerals is expressed in terms of Mohs' scale. Formulas and other physical constants have been taken from Dana* as far as possible. Brief explanations concerning physical properties are supplied in the Appendix, together with other general information pertinent to the subject.

Bibliographies have been selected with the intent of preserving the most valuable and informative material. Many of these references contain extensive bibliographies in which research may be carried further.

The authors are painfully aware of the intricate structure of the nonmetallic industries and the speed with which technology has progressed during the past few years. A completely up-to-date summary of the technical status of the field is an impossibility. It is hoped that this edition will serve to cover in reasonable detail the most important developments in the field.

* DANA, JAMES, and SALISBURY, EDWARD, "The System of Mineralogy," 7th ed., John Wiley & Sons, Inc., New York, 1944.

ABRASIVES

Natural abrasives have an ancient history; they were used by Paleolithic man to shape and polish tools and weapons made of flint, horn, and bone. The lack of knowledge of metals in perhistoric times was so pronounced that abrasives were probably the first tools whose utility was recognized. Many minerals have been employed as abrasives, and among them quartz continues to be the most useful. This is due to the hardness of the mineral, its extensive geographic and geologic distribution, its occurrence in many states of form and subdivision in the common sands and rock, and the economy with which it can be produced. Flint, chalcodony, and tripoli, close relatives of quartz with a high percentage of silica in their composition, are similarly employed.

A certain amount of abrasion is associated with crushing, grinding, and polishing, and at times it is difficult to differentiate between these processes. The milling of grain or the grinding of feldspar, talc, and similar minerals to comparable size was accomplished in the past by the use of natural abrasives. Smoothing rough metal surfaces on castings and polishing to an even surface were done for years by the application of sand and emery. Fine polished surfaces on glass, gem stones, varnished wood, and related materials were obtained by the use of similar products. In these fields natural abrasives have encountered increasing competition from metallic grinding equipment designed for the operation and from artificial abrasives manufactured from mineral raw materials. Nevertheless, the production of natural abrasives continues to form the basis of a small but useful mineral industry. This survival has been due to certain physical properties which some of these materials possess and which cannot be duplicated readily. Economy in production and transportation costs, and in some cases freedom from metallic iron or iron-bearing impurities, have contributed to the survival of their industrial position. Their efficiency depends upon toughness, hardness, shape of the individual particle, size of the individual particle, and breaking characteristics during use whereby new cutting edges are exposed; without these characteristics the abrasive grain is polished to a smooth surface with little cutting efficiency. The selection of an abrasive with proper hardness for the work in hand is highly important. Too great hardness may become highly objectionable by producing a cutting action that is so rapid as to cause damage rather than benefit. The abrasive used in tooth paste must be soft enough not to injure the enamel of the tooth, and similarly the abrasive employed in soap or cleaning compounds must be chosen to prevent scratching of the glass, tile, or polished stone upon which it may be used. The size of the abrasive grain is dependent upon the degree of grinding necessary. Thus, coarse grinding is done with coarse grain, and progressively finer sizes are employed as the surface becomes smoother, the final polishing being done with

powders of extreme fineness prepared by air flotation or water levigation. The selection of an abrasive is dependent upon satisfactoriness of performance, quantity of performance, and cost as compared with other materials. Artificial abrasives have replaced natural abrasives in many operations connected with metal grinding, in spite of their higher cost, due to their superior performance and compensating saving in labor costs.

Hardness. The property of hardness is imperfectly understood and in minerals cannot be measured with accuracy. The same difficulty exists in other materials. Standardized procedures of testing are recognized by which comparable results are obtained although they do not actually represent true hardness. If hardness be defined as "resistance to abrasion" one of the hardest materials known is the rubber automobile tire, which will roll for thousands of miles on the highway after a steel tire has been destroyed. The property of resilience, therefore, has an important effect upon true hardness. Hardness in minerals is expressed in relative terms by what is known as "Mohs' scale." In this scale talc (1) is the softest, and diamond (10) is the hardest. The gap in hardness between Nos. 9 and 10 is believed to be greater than the gap between Nos. 1 and 9. The scale expresses no absolute values, therefore, but only relative degrees.

Mohs' Scale

1. Talc	6. Feldspar
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corundum
5. Apatite	10. Diamond

See also Appendix, Scale of Hardness.

With a few notable exceptions minerals occur in the crystalline state; therefore, they follow one of the basic laws of crystal behavior. Their properties vary with direction. Hardness is one of these properties; certain minerals (for example, kyanite) appear to be much harder at right angles to the principal axis than parallel to the axis. The diamond displays a similar variation in hardness with direction; the octahedral face is much the harder. Since the mineral has a pronounced octahedral cleavage along which it naturally breaks, fragments produced by crushing exhibit a large number of surfaces parallel to the octahedron. Diamond powder, therefore, can be used as an abrasive to polish facets on a gem stone, none of which in the standard brilliant cut is parallel to the octahedron. It is recognized now that the great variation in the efficiency of diamond tools was due to random setting of the stone, with the result that proper orientation frequently was not obtained, and the diamond was not so placed as to perform at maximum capacity.

In Mohs' scale it is noteworthy that quartz is No. 7 and therefore in a position of exhibiting a hardness superior to most common minerals. Harder materials are comparatively rare and are found in only a few localities. Quartz is one of the most widely distributed and abundant minerals. It is therefore the most important natural abrasive.

NATURAL ABRASIVES

Those in Which Some Form of Quartz Is Dominant.

1. Buhrstones
2. Chaser stones
3. Flint
4. Grindstones and pulpstones
5. Holystones
6. Grinding pebbles and tube-mill liners
7. Millstones
8. Sand
9. Sharpening stones, oilstones, whetstones, scythestones
10. Siliceous clays and rottenstone

A portion of the production of a number of other minerals is diverted to abrasive use. Data pertinent to this use will be found under Chalk, Corundum and Emery, Diamond, Diatomaceous Earth, Feldspar, Garnet, Gypsum, Lime, Pumice, Quartz, Sand, Tourmaline, and Tripoli.

Forms in Which Abrasives Are Used.

1. Loose grains and powders
 - a. Stone surfacing and polishing
 - b. Glass surfacing and polishing
 - c. Sand blasting
 - d. Sand with wire saw
 - e. Cleaning compounds
 - f. Grinding and polishing on wheels, buffers, etc.
 - g. Tooth powders
2. Hand sharpening stones
 - a. Natural stone cut to shape
 - b. Bonded abrasive grains
3. Grindstones
 - a. Natural stone cut to shape
 - b. Bonded abrasive grains
4. Grinding wheels
 - a. Natural stone cut to shape
 - b. Bonded abrasive grains
 - c. Impregnated metal
 - d. Chaser-mill stones, paint-mill stones, rubbing stones for wood, concrete, etc.
5. Drills
 - a. Set in metal
 - b. Impregnated metal
6. Buhrstones
 - a. Natural stone cut to shape
 - b. Blocks of natural stone or artificial abrasive set in cement

7. Coated abrasives
 - a. Paper backing
 - b. Cloth backing
8. Pastes and soaps
 - a. Hand soaps
 - b. Cleaning soaps
 - c. Metal polishes
 - d. Valve-grinding compounds
 - e. Tooth pastes
9. Brick (as "bath" brick)

Buhrstone is, properly speaking, a tough porous stone consisting almost entirely of silica, used originally as horizontal millstones for grinding grain. The term "buhrstone" now is applied to other types of stone used for the same and other purposes. The best true buhrstone is found in France, chiefly in the mineral basin of Paris, where it occurs in large masses. It is white, gray, yellow, or bluish in color and varies in texture from very open and porous to close grained. It has a straight fracture and is not so brittle as flint, although of about the same hardness. It is worked in open quarries and usually sold in regular blocks, which later are dressed to proper size, fitted together, and bound into solid wheels. Similar material occurs in Belgium. German buhrstone is a basaltic lava found near Cologne.

True buhrstone is not produced in the United States. Domestic stones used as buhrstones are considered under Millstones. Buhrstones have been used in the United States in the grinding of paint, a use which is continued in a small way. In other fields it has been replaced almost entirely by more modern equipment.

Chaser stones are large circular stones, run on edge, used for coarse grinding. A common size is 6 ft in diameter with a face 18 to 22 in. wide. Sandstone, quartzite, and granite have been used for this purpose. At one time they were employed extensively in the grinding of feldspar and quartz. They were rotated, frequently by water power, on a stone pavement composed of blocks of the same material used for the chaser. Crushed rock was thrown on the pavement and reduced in size by the weight of the chaser passing over it. The ground material as displaced by the chaser was shoveled back under the chaser until reduced to the size desired. Final grinding to desired size (—100 mesh or finer) was done in batch mills. This equipment possessed one advantage: no metallic iron was introduced in the ground material, an important point in ceramic raw materials. The use of chaser mills has declined drastically in the past 25 years.

Flint. True flint, which is a chalcedonic variety of silica, is used as an abrasive chiefly in the form of grinding pebbles and as a liner in tube and pebble mills. It has been used to a small extent, after crushing and grinding, for coating abrasive papers. Flint from the chalk cliffs of England has been used for this purpose. Flint will abrade steel and under impact the abraded particles will oxidize with such rapidity as to ignite. Flint and steel have been used as an igniter of gunpowder and as a source of fire for many years. Mineral prospectors in remote areas still carry flint and steel. Flint for use in muzzle-loading flint-

locks is still prepared by the English flint knappers and forms a very small industry at Brandon in Suffolk County.

Grindstones and Pulpstones. The production of grindstones and pulpstones has shown a long-continued decline in value and industrial importance due to the increased use of artificial abrasives. These stones are manufactured almost exclusively from sandstone. The grains of sand in the sandstone may be cemented with quartz, calcite, clay, or limonite. Calcite may be objectionable due to its solubility, and limonite or clay due to the weakness of the bond.

Northern Ohio and West Virginia are the most important districts in the United States for the production of grindstones and pulpstones. Near Cleveland an extensive bed of lower carboniferous sandstone, known as the "Berea grit," is worked extensively. In this area and in other districts in Ohio and Michigan a number of different "grits" or types of abrasive sandstone have been worked. These are as follows:*

1. The Berea grit (Ohio), a fine, sharp grit, is used especially for sharpening edged tools, such as farmers' tools and woodcutters' small tools.
2. The Amherst grit (Ohio), which is both soft and loose, medium and loose, and fine, is used especially for edged tools, saws, etc., in manufacturing plants where the grindstone is operated by power.
3. The Independence grit (Ohio), a coarse, sharp grit, is used for grinding springs and files and for dry grinding of castings.
4. The Massillon grit (Ohio), a coarse, sharp grit, is used for grinding large edged tools, springs, files, and dry castings.
5. The Tippecanoe grit (Ohio), a fairly loose, hard grit, is used for grinding wood pulp, springs, files, and heavy forgings.
6. The Marietta grit (Ohio), a soft, loose grit, is used largely in grinding saws, machine knives, and other high-tempered, thin steel tools.
7. The Huron grit (Michigan), a fine, sharp grit, is used for cutlery, mowing-machine sections, and similar tools where a fine edge is required.
8. The Peninsula grit (Ohio), a hard, coarse grit, is used for grinding wood pulp.
9. Euclid stone (Ohio) contains about 70 per cent fine silica and 30 per cent clay. It is used for whetters, principally in cutlery works, for polishing out scratches made by ordinary grindstones.

A grindstone made from a coarse, hard sandstone, used particularly for razor grinding, is produced in Bavaria. Merrill also notes the following additional grits:

The Joggins (Nova Scotia). Fine gray; of uniform texture; used for wet-grinding all kinds of edge tools; the large stones for grinding springs, sad irons, and hinges; extensively exported to the United States.

Bay of Chaleur (New Brunswick). Fine dark bluish gray; of firm texture; smells strongly of clay when breathed upon. Resembles the stone of Huron, Mich., but contains less mica. Used in the manufacture of table cutlery; also machinists' tools and edge tools in general.

Newcastle (England). Light gray and yellowish; with a sharp grit; rather friable, and texture somewhat coarser than that of the Berea stone, which it otherwise somewhat resembles. The finer grades used for grinding saws and the coarser and harder

* These grit names are derived chiefly from names of the typical producing centers.

ones for sad irons, springs, pulleys, shafting, for bead and face stones in nailwork, and for the dry grinding of castings; also used by glass cutters.

Wickersly (England). A dull brownish or yellowish, somewhat micaceous stone of medium texture and rather soft. For grinding saws, squares, bevels, and cutlers' work in general.

Liverpool, or Melling (England). Dull reddish; a somewhat loosely compacted aggregate of siliceous sand, so friable that the sharp angles are easily crumbled away by the thumb and fingers. A very sharp grit, used for saws and edge tools, particularly axes in shipyards.

Craigleith (Scotland). Fine grained and nearly white. A very pure siliceous sandstone with a sharp grit. Said to be the best stone known for glass cutting, though the Newcastle, Warrington, and Yorkshire grits are also used for a similar purpose.*

Grindstones are made in several ways. By one method the stone is removed from the quarry in rectangular blocks and then split nearly to, or sawed directly to, the desired thickness. A circle of the desired diameter is then marked out, and the stone rough-hewed to the mark. A square hole is then cut in the center, and the stone is mounted on a heavy, square iron shaft, to which the stone is fastened by collars. The shaft and the stone are then rotated by power and two men, on opposite sides of the stone, turn it down perfectly true by means of soft-iron bars 6 ft long by 2 in. wide by $\frac{1}{2}$ in. thick, drawn out to a thin, upturned edge.

In some quarries a circle of the desired size is laid out on a level surface of the stone in the quarry. Holes as deep as the desired thickness of the stone are then drilled close together around the circle, and the web broken out between. The stone is then loosened by wedging, lifted from the quarry, and finished by turning.

A more recent technique has been described by Random.⁹ Cylindrical blocks of specified diameter are cut in place in the quarry floor by the use of a circular steel cutter employing steel shot as an abrasive. When the depth of cut has reached the desired dimension, the disk of stone is liberated from the bedrock. This is accomplished by drilling a horizontal hole at the base of the disk and shooting a small charge of explosive. The stone block is then removed from the quarry, sawed in thinner blocks if desired, and prepared for use by cutting a square hole in the center and trimming the sides and face in a lathe. Aging of pulpstones is important. The stones as removed from the quarry are saturated with water, sometimes called "quarry sap." This contains silica in solution, which is deposited upon evaporation of the solvent, acting as a cement and improving the quality of the stone. Stones may be aged from 1 to 2 years before shipment.

Pulpstones are heavy grindstones used for grinding wood into fine fiber for making paper pulp. Disks from 27 to 54 in. in thickness and from 54 to 62 in. in diameter, weighing from 2 to 4 tons, are employed. Production in recent years has been restricted to the state of Washington and West Virginia. Manufactured abrasives have become a competitor in this market.

Holystones are composed of material similar to grindstones. They are used, mostly on shipboard, for cleaning and rubbing down wood surfaces, such as ship decks.

* MERRILL, G. P.: "The Non-metallic Minerals," 2d ed., pp. 404-405, John Wiley & Sons, Inc., New York, 1910.

Grinding Pebbles and Tube-mill Liners. Rounded flint pebbles are used in tube and pebble mills for grinding certain minerals and to a limited extent for the grinding of ores. Their use is advantageous in the grinding of such materials as potter's flint or feldspar where the avoidance of contamination by metallic iron is desirable. The most important sources are along the seacoast near Havre, France, and in Belgium and Greenland. Pebbles from Greenland are sent to Denmark and are known in the trade as "Danish flint." These pebbles are considered as the standard for comparison due to their great hardness and toughness. Total imports have seldom exceeded 20,000 tons in a single year. A portion of this material has been diverted for use as potter's flint. The actual tonnage consumed as an abrasive, therefore, has always been small.

Interference with shipping in the First and Second World Wars resulted in an increased interest in domestic supplies. A number of rocks and minerals have been employed. In 1942 a maximum tonnage was reported. Recent production is shown in Table 1.

TABLE 1. GRINDING PEBBLES AND TUBE-MILL LINERS SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948

Year	Grinding pebbles		Tube-mill liners		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944	8,012	\$172,418	2,063	\$38,833	10,075	\$211,251
1945	8,615	201,806	1,982	45,933	10,597	247,739
1946	4,652	102,043	2,375	44,247	7,027	146,290
1947	5,860	122,883	1,496	40,303	7,356	163,186
1948	4,026	101,583	1,297	41,555	5,323	143,138

Grinding pebbles were produced in California, Minnesota, North Carolina, Texas, Washington, and Wisconsin. Beach pebbles, artificially rounded quartzite, rounded granite, flint, and quartzite pebbles were recovered and prepared for the market. Tube-mill liners were manufactured from quartzite and granite in Minnesota, North Carolina, Wisconsin, and South Dakota.

Millstones. Sandstone and quartz conglomerate are used for millstones. The industry has declined in the face of competitive equipment to the extent that in 1946 the total output was valued at \$14,780. New York was a leader in the production of this material for many years when it was of greater importance. Esopus stone quarried from the Shawangunk conglomerate near Kingston was a well-known stone, as was the Brush Mountain stone from Montgomery County, Va. Production continues from these deposits in a small way. There is also a limited output from Minnesota and North Carolina where granite is used. Chaser stones have been produced from the same localities. Millstones were finished in flat circular form and fluted radially. One was placed upon another, one stationary and the other revolved, frequently by water power. Corn, wheat, and other grains are introduced through an opening in the upper stone and dis-

charged in ground form at the periphery. This is one of the most ancient milling devices and was adopted by the mineral industries in the early stages of development for the fine grinding of talc, gypsum plasters, mineral pigments, and similar materials. Except for a few special uses and their retention in a limited number of gristmills they have been displaced by modern milling methods.

Sharpening Stones (Oilstones, Whetstones, Scythestones, and Hones). Under the head of Natural Sharpening Stones come a variety of natural stones used for sharpening all kinds of small hand tools and instruments. Some of these stones are used dry, such as scythestones; and on some, oil (oilstones) or water (water stones) is used to float away the small particles of metal, cut away in the sharpening process, which would otherwise clog the pores of the stone, causing it to glaze over and eventually become useless.

Natural sharpening stones are more commonly made from ordinary sandstone, fine to medium-coarse grained; from novaculite, an exceedingly fine-grained crystalline sandstone; and from quartz-mica schist; but other types of stone are sometimes used.

Although abrasive stones are found in nearly every state east of the Mississippi and in many of the western states, there are relatively few producing localities. The more important districts in the United States are noted below.

Arkansas. Arkansas oilstones, produced principally in the vicinity of Hot Springs, Garland County, are of two varieties: Arkansas stone, which is a true novaculite, and Washita (originally Ouachita) stone, which is less dense and more porous than true novaculite.

The Arkansas stone, produced in "hard" and "soft" grades, is an exceedingly fine, sharp-grained white stone with a conchoidal fracture and waxy luster. It contains about 99½ per cent cryptocrystalline silica. It is used for sharpening very fine-edged instruments and small tools.

The Washita stone has about the same composition as the Arkansas stone but is less dense and more porous; it has the luster of unglazed chinaware and a sub-conchoidal fracture. It is marketed in several grades, which, descending in the order of quality, are "Lily White," "Rosy Red," "Extra," "No. 1," and "No. 2." It is a somewhat faster cutting stone than the Arkansas, is less expensive, and is used for somewhat coarser work.

Oilstones are used after grinding to eliminate burr. An oilstoned tool possesses a keener, firmer edge which will not break down in service as soon as that of an untreated tool; its life is thereby prolonged between grindings.

Indiana. The sandstones of Orange County, Ind., furnish a whetstone known as the *Hindostan* or *Orange* stone, which has been quarried in French Lick and Northwest townships. The stone is fine grained and is used as a low-priced oilstone for mechanics' use.

Ohio. A number of the sandstone beds of Ohio, particularly the Berea and Euclid grits (noted under Grindstones), furnish material suitable for oilstones and scythestones. Some of the localities in which such stones have been produced are Berea and Euclid, Cuyahoga County, and Grafton, Lorain County. The *Deerlick* stone is produced at Chagrin Falls, Cuyahoga County. The *Queer Creek* is a hard, medium-coarse-grained Ohio sandstone, dark gray in color, sold as an inexpensive stone for rather coarse sharpening.

New York. Near Labrador Lake, Cortland County, N.Y., a sandstone similar to that quarried in Ohio has been produced. It is known as *Labrador stone* and has been used to a small extent for whetstones.

New Hampshire and Vermont. In Haverhill Township, Grafton County, N.H., and near Lamoille, Orleans County, Vt., there is a quartz-mica schist from which are manufactured the well-known *Indian Pond*, *White Mountain*, and *Lamoille* scythestones. At Lisbon, Grafton County, N.H., a similar schist occurs of a bluish-chocolate color, which furnishes a stone known as the *chocolate* whetstone.

Stones from Other Countries. The *water of Ayr*, *Scotch hone*, or *snake stone* is a very compact schist produced at Dalmour, in Ayrshire, Scotland. This stone is used for whetstones and hones, for burnishing purposes, and as lithographic stones.

The *Turkey oilstone*, which resembles Arkansas novaculite in structure and abrasive qualities, is produced in Smyrna, Asia Minor. Before the discovery of the Washita stone it was for many centuries the leading oilstone for mechanics' tools. It is composed of about 70 per cent silica with 30 per cent lime, clay, and iron. It is not so uniform as the Washita stone and is now little used in the United States.

The *Belgian razor hone*, quarried at Lierreux, Sart, Salm-Chateau, Bihau, and Rect in the Ardennes of Belgium, is a damourite slate containing innumerable garnets, more than 100,000 per cubic inch. It occurs (like the Ratisbon hone) as thin, yellowish bands, about $2\frac{3}{8}$ in. wide, in a blue-gray slate. The bands are essentially parallel with one another and with the grain of the slate. The cutting power of the stone seems to be due to the small garnets. This hone is sometimes called "petrified wood hone," "soap hone" or "oil hone." Hones are cut from this stone in such a way that a layer of the blue slate serves as a backing for the softer yellow sharpening surface.

The *German water hone* is a fine, hard, blue-green, slaty mica schist from Sonneberg, Germany.

Rottenstone. Rottenstone is a material resembling the Missouri-Oklahoma type of tripoli (see page 561), derived as a residual product from the weathering and the decay of a siliceous-argillaceous limestone. It occurs as a soft, friable, loosely coherent, earthy mass of light-gray to brownish- or olive-gray color. It is often sufficiently coherent to be used in the form of bricks. It varies considerably in chemical composition, but alumina is the predominant constituent. Analyses show: alumina (Al_2O_3), 80 to 85 per cent; silica (SiO_2), 4 to 15 per cent; carbon (C), 5 to 10 per cent; iron oxides, 5 to 10 per cent; and small amounts of lime.

Most of the true rottenstone used in the United States is imported from Hull and from Wales, England, but some is also imported from Belgium.

A so-called American or domestic "rottenstone" is produced at Antes Forte, Lycoming County, Pa. An analysis of this material shows that it contains about 60 per cent silica, $8\frac{1}{2}$ per cent alkalies, $17\frac{1}{2}$ per cent alumina, 9 per cent iron oxides, 1 per cent moisture, and 3 per cent lime and magnesia. This analysis, together with an examination of the crude rock, both microscopically and with the unaided eye, shows that this material is not true rottenstone but probably a ferruginous and siliceous shale. It is noticeably heavy, while true rottenstone is very light.

True rottenstone is finely ground and bolted and sold, either in the form of a powder or molded into rottenstone brick. It is used in wood and metal finishing and as a filler material.

The Pennsylvania rottenstone is quarried, crushed in a jaw crusher, dried in a rotary direct-heat drier, and ground in a Raymond mill equipped with the Raymond system of air separation. The fine powder is elevated to bins, from which it is bagged by automatic packers. Two products are made regularly, a 250-mesh product used as a filler, chiefly in phonograph records, and a coarser grade for the polishing trade.

Methods of Mining and Manufacture. Mining, mostly quarrying, requires a skillful recognition of the geologic structures in which the best material is found. The major problem is the recovery of sound material in maximum size with a minimum of waste. Careful selection at the quarry is necessary to eliminate material with incipient fractures, included impurities, or cavities that might render the stone worthless after considerable expense had been incurred in manufacturing operations. Workable stone is recovered in rather small pieces. These are trimmed and sawed to size. Stones for use on fine-edged tools are rubbed to a plane surface.

SURFACE-COATED ABRASIVES

Coated abrasives consist of strips of cloth or paper to which sized abrasive grains have been cemented. Sandpaper, garnet paper, and emery paper are the most important types using natural abrasives. Sand has not been used for years, having been replaced by the more efficient crushed quartz. Corundum, fused alumina, and carborundum are also used. All abrasive grains for this purpose must be sized accurately. This involves crushing, classification, drying, removal of magnetic iron-containing minerals or metallic iron, and final screening to produce a grain of specified dimension. Fine powders are produced by levigation. The sized grains are distributed uniformly over the surface of the paper or cloth, which has been coated with glue or an adhesive not soluble in water. An electrostatic process is employed to obtain a more uniform distribution of the grain and better orientation of the individual grain. Adherence of the grain to the glue is increased by a coating treatment. Grains so treated will fracture rather than pull out, permitting faster cutting and longer use of the abrasive. The abrasive grain is reported to be coated with molybdenum-containing frit of low melting point.¹ Subsequent application of an inert pigment produces a roughed surface promoting good adherence of the adhesive to the grain. Surface-coated abrasives are supplied in sheets, disks, and belts for use in mechanized equipment. They are particularly useful in the finishing of the surfaces of wood, leather, metal, and plastics. The relationship of screen-mesh size to the numbers used to designate grain size for common abrasive grains is shown in Table 2.

ARTIFICIAL ABRASIVES

Artificial abrasives originated in 1891 when Edward Acheson first prepared silicon carbide in the electric furnace. This material is now sold under a number

of names, such as "carborundum" and "crystolon." The superior hardness of this material and the ability of the grains to shatter under use, presenting new cutting surfaces, resulted in its rapid adoption in many fields previously dominated by natural abrasives. This was followed by the introduction of aluminum oxide. The production of silicon carbide and aluminum oxide is concentrated in the Niagara Falls district of Canada and New York, where electrical energy can be obtained economically. Fused alumina is employed in the manufacture of about 75 per cent of the grinding wheels produced. The use of such wheels has revolutionized the grinding, shaping, and polishing of metallic objects.

TABLE 2. ABRASIVE GRAIN MARKINGS

Mesh of screen	Garnet	Emery	Flint
400	10/0		
320	9/0		
280	8/0		
240	7/0		
220	6/0		4/0
180	5/0	3/0	3/0
150	4/0	2/0	2/0
120	3/0		
		1/0	1/0
100	2/0		
		$\frac{1}{2}$	$\frac{1}{2}$
80	1/0	1	1
60	$\frac{1}{2}$	$1\frac{1}{2}$	
50	1	2	$1\frac{1}{2}$
40	$1\frac{1}{2}$	$2\frac{1}{2}$	2
			$2\frac{1}{2}$
36	2	3	
30	$2\frac{1}{2}$		3
24	3		$3\frac{1}{2}$
22	$3\frac{1}{4}$		
20	$3\frac{1}{2}$		
18	$3\frac{3}{4}$		
16	4		
14	$4\frac{1}{4}$		
12	$4\frac{1}{2}$		

Manufacture of Grinding Wheels. The efficiency and performance of the abrasive wheel depend upon the type and size of grain employed and upon the bond and the density or porosity of the finished product. The wheel with a vitrified bond is in most common use and supplies about 75 per cent of all the wheels in use. The abrasive grains of selected size are molded in shape with a mixture of feldspar, clay, and silica similar to that used in a ceramic body. The wheel is then fired in a kiln at a temperature of 1275°C. This ceramic bond is

not affected by water, weathering, mild acids, or oil. It is limited in use to a speed of 6,500 sfpm.

The silicate bond is produced by the use of sodium silicate, or water glass. The abrasive grain is mixed with this material, pressed in a mold, and baked at 250°C from 1 to 3 days. This bond does not hold the individual grains so closely as the vitrified bond, but makes a softer wheel particularly suitable for edged tools.

Shellac is employed as a bond, mostly for fine grits used for finishing jobs on metals and edges on tools and saw teeth. The shellac is mixed with the abrasive grain in a steam-heated machine, molded in a hydraulic press, and baked for a few hours at 150°C. Plastic or resin bonds are replacing shellac, since they are more uniform in composition and behavior.

Rubber is used as a bonding agent. Such wheels are suitable for operation at high speed and for cutting off and sawing metals. The thinnest wheels, such as are used for slitting points of pens, are made from rubber-bonded material. The rubber, abrasive, and sulfur (the vulcanizing agent) are mixed, rolled, and cut in disks, which are baked in molds.

Resinoid bonds, produced by the use of plastics, bakelite, glyptol, and similar materials, are in common use. In the manufacture of such wheels the abrasive is moistened with a plasticizer, mixed with resin and filler, spread in a mold, compressed to size, and heated and cured in an oven at a temperature of around 160°C. These wheels can be operated at high speed and withstand hard use.

Grinding wheels are used for the coarse grinding or snagging of castings; precision grinding to size and shape; cutting metals; producing sharp edges; and for the shaping and smoothing of metals, wood, and plastics in hundreds of industrial operations. Pulpstones up to 6 ft in diameter and 4 ft thick have been built up from blocks of artificial abrasives and, as has been noted, their use has reduced the market for those of natural origin.

Metallic abrasives, including steel shot and grit, are manufactured in a number of states. Ohio, Michigan, and Pennsylvania are the principal producers.

Many new products are appearing in the abrasive markets. Boron carbide (B_4C), an electric furnace product, is prepared by the fusion of boric acid (B_2O_3) and carbon at a temperature of around 2800°C. This is possibly the hardest substance known, except diamond, being approached only by other carbides, such as tungsten, tantalum, and titanium. Many metallic oxides such as crocus and rouge, oxides of iron, tin oxide, chromium oxide, aluminum oxide, manganese oxide, and magnesium oxide are used for fine polishing on glass, gem stones, and metallic surfaces. Cerium oxide is one of the latest metallic oxides to be used for fine polishing.

Testing of Abrasives. No uniform or standardized methods are available for testing abrasives. The most satisfactory test is to prepare the material in question in the form in which it is to be used and to compare its efficiency in actual use with that of materials now acceptable to industry. Since most manufacturing processes cannot be duplicated in the laboratory, the most feasible procedure is to submit samples of the material to be tested to companies that fabricate or deal in abrasive materials. The comparative hardness of natural abrasives and electric

furnace products has been determined by measuring the relative resistance during lapping. The materials to be tested are so mounted that they can be abraded by a grinding wheel supplied with a standard abrasive grain. The amount of relief obtained by lapping, which is measured with great accuracy, is proportional to the hardness, the harder material naturally projecting the greatest distance.¹⁴

The magnitude of the abrasive industry, natural and artificial, as measured by tonnage and value is shown in Table 3.

TABLE 3. SALIENT STATISTICS OF THE ABRASIVES INDUSTRIES IN THE UNITED STATES, 1945 TO 1946

	1945		1946		Per cent of change in 1946	
	Short tons	Value	Short tons	Value	Short tons	Value
Natural abrasives:						
Domestic production (sold or used by producers):						
Diatomite.....	174,957 ^a	\$3,298,178 ^a	174,957 ^a	\$3,298,178 ^a		
Tripoli.....	18,247	306,829	28,955	549,099	+59	+79
Quartz.....	57,764	236,803	73,179	293,852	+27	+24
Ground sand and sandstone.....	533,656	3,709,597	575,888	4,125,398	+8	+11
Grindstones.....	10,033	399,565	11,605	501,444	+16	+25
Pulpstones.....	^b	^b	72	3,880		
Oilstones and related products.....	^c	^c	^c	^c		
Millstones.....	^d	15,018	^d	14,780	....	-2
Tube-mill liners.....	1,982	45,933	2,375	44,247	+20	-4
Grinding pebbles.....	8,615	201,806	4,652	102,043	-46	-49
Pumice and pumicite....	157,011	1,051,037	319,883	1,585,753	+104	+51
Garnet.....	6,306	375,198	7,743	570,186	+23	+52
Emery.....	7,856	75,977	6,188	62,099	-21	-18
Total natural abrasives ^e	980,780	\$9,801,988	1,205,497	\$11,150,959	+23	+14
Artificial abrasives:						
Silicon carbide production ^e	53,773	4,238,655	63,849	5,457,903	+19	+29
Aluminum oxide production ^e	147,016	9,130,093	132,084	8,367,158	-10	-8
Metallic abrasives (steel shot and grit) shipments.....	146,771	8,524,073	111,512	6,387,819	-24	-25
Total artificial abrasives	347,560	\$21,892,821	307,445	\$20,212,880	-12	-8
Total abrasives.....	1,328,340	\$31,694,809	1,512,942	\$31,363,839	+14	-1
Foreign trade:						
Imports.....	^b	13,493,381	^b	15,320,284	....	+14
Exports.....	^f	2,087,598	^f	2,426,853	....	+16

^a Average annual figure for 1942 to 1944; Bureau of Mines not at liberty to publish 1945 and 1946 data.

^b Data included in total; Bureau of Mines not at liberty to publish figures.

^c Data for oilstones and related products not included in totals; Bureau of Mines not at liberty to publish figures.

^d Tonnage of millstones not recorded.

^e Includes Canadian production.

^f Weight cannot be reported because of varying units.

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ACTINOLITE

Composition. Actinolite is a calcium, magnesium, iron silicate, $\text{Ca}(\text{Mg}, \text{Fe})_3(\text{SiO}_4)_3$.

General Description. Actinolite, a type of amphibole, usually occurs as green, bladed crystals in irregular divergent or columnar fibrous aggregates, also in compact granular masses. It alters to talc, chlorite, epidote, or an aggregate of serpentine and calcite.

Physical Properties. *Hardness*, 5 to 6. *Specific gravity*, 2.9 to 3.2. *Melting point*, 1322 to 1346°C. *Index of refraction*, 1.611 to 1.636. *Color*, bright green to grayish green. *Streak*, white. *Luster*, vitreous to silky. *Cleavage*, perfect

prismatic at angles of 56 and 124 deg. *Transparency*, transparent to opaque. *Tenacity*, brittle.

Occurrence, Production, and Utilization. Actinolite is a common mineral in metamorphosed rocks, such as schists and gneisses, but production has been reported from only one locality. Large deposits of actinolite occur in south-eastern Ontario, Canada.

These deposits have been described by W. G. Miller and C. W. Knight, from whose report the following has been taken:

Large bodies of actinolite occur in the townships of Elzevir and Kaladar in Hastings and Addington counties. Hundreds of tons of the material, with which is often associated serpentine or talc, have in past years been ground and used for roofing purposes. Buildings in several cities of the United States are roofed with this material. None of the occurrences are at present being worked. [There are] seven of the more important open cuts, from which the actinolite has been shipped. . . . Some of these occur on lots 4 and 5 in the seventh concession of Elzevir township, about 3 miles east of the village of Actinolite. The material here is clearly a metamorphosed basalt, or other greenstone, of the Keewatin series, which has been altered by the great intrusion of Laurentian granite gneiss. The latter sends immense dikes into the greenstone and holds great blocks of it. In places the greenstones has entirely altered to serpentine, which contains stringers of asbestos a fraction of an inch in width. This may be seen on lot 4 in the seventh concession of Elzevir.

The largest belt of actinolite occurs on lots 7 and 8 in the eleventh concession of Elzevir, crossing into lots 8 and 9 in the first concession of Kaladar. The actinolite here has associated with it little or no serpentine. It occurs in the form of a lens a mile and a half long and 600 or 700 ft wide, closely enfolded in the Hastings conglomerate. . . .²

Some of the actinolite appears to be suitable for decorative purposes, as, for example, the lens that occurs on lot 12 in the second concession of Kaladar, 4 miles southwest of the village of Flinton. This occurrence is found at the contact of a mica and chlorite schist and granite. The actinolite here has a beautiful radiated texture and some large blocks have been quarried and shipped from Kaladar station.

Actinolite was first ground in Ontario for roofing in 1883 at the village of Actinolite, which, at that time, was called Bridgewater. The process consisted of crushing in a Blake crusher and grinding in attrition mills to 60 mesh without destroying the fiber. Water power was obtained from the Skootamatta River. A proportion of mica was added to increase the bond. When applied to a roof, 11 gal of coal tar, or its equivalent, was mixed with 100 lb of the ground material and the mixture was spread on the roof while hot, the total thickness, including the felt on which it was spread, being $\frac{1}{2}$ in. For 6 or 7 years after operations began in 1883, the value of the output was \$6,000 per annum. Following this the mill was operated at intervals, but statistics regarding production are not available until the years 1901, 1902, and 1903, when the output was valued at \$3,126, \$6,150, and \$1,650, respectively. The industry was brought to a standstill in June, 1904, by the destruction of the mill dam.

It may be added that a new mill has recently been constructed at the Actinolite

railway station, but the output to date has been very small, some 32 tons being produced in 1910. The largest production in any year was about 550 tons in 1902 or 1903.

In 1934, 30 tons valued at \$365 was reported to have been recovered. The reserve in this area for any possible future use is the greatest known in eastern America.

Bowles¹ reports the occurrence of a green metamorphic rock, essentially actinolite and chlorite, at Lynchburg, Va. It is quarried and sold as an antislip material being incorporated in floors to prevent accident.

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ALUM MINERALS

The alums, which are soluble, crystallized, double sulfates of potash, sodium, iron, ammonium, aluminum, chromium, and other elements, usually characterized by easy solubility in water and a strongly astringent taste, are represented by a number of minerals, most of which do not occur in important quantities. Much of the alum in commercial use at present is made, directly or indirectly, from bauxite, clays, alunite, and cryolite; but natural alums are of some importance, particularly in foreign countries. It is quite possible that some of the deposits of natural alums in the United States which are not now worked—for example, those near the Gila River, Grant County, N.M., described below—may be of considerable future importance. The natural alums, because of their easy solubility in water, are not found in quantity except in arid regions or in places, such as caves, that are protected from moisture.

The principal alum minerals are described below. Aluminite, an insoluble but analogous mineral, is also described. Alunite, another closely allied mineral from which alum has been made, is described in the section devoted to that mineral. The natural alums known to occur in the United States possess some potential commercial interest but never have become industrial producers comparable to those in England.

ALUNOGEN

Composition. Alunogen is a hydrous aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$: Al_2O_3 , 15.3 per cent; SO_3 , 36 per cent; H_2O , 48.7 per cent. It is not, strictly speaking, a true alum, since it is not a double sulfate.

Physical Properties. *Hardness*, 1.5 to 2. *Specific gravity*, 1.6 to 1.8. *Melting point*, melts in its own water of crystallization, but finally becomes infusible

at ordinary temperatures. *Index of refraction*, 1.474 to 1.483. *Color*, white, yellowish, or reddish. *Streak*, white. *Luster*, vitreous or silky. *Cleavage*, usually fibrous. *Transparency*, translucent. *Tenacity*, brittle. Readily soluble in water. *Taste*, astringent, like alum.

General Description and Mode of Occurrence. Alunogen usually occurs as white, yellowish, or pinkish fibrous crusts, but sometimes massive or powdery. It is formed by the action of sulfuric acid, from decomposing sulfides or from volcanic sources, upon aluminous shales or other aluminous rocks; also as a sublimation by volcanic action.

HALOTRICHITE

Composition. Halotrichite is a hydrous double sulfate of iron and aluminum, or a natural iron alum, having the formula $\text{FeSO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$: $\text{Al}_2(\text{SO}_4)_3$, 36.9 per cent; FeSO_4 , 16.4 per cent; H_2O , 46.7 per cent; or Al_2O_3 , 11.0 per cent; FeO , 7.8 per cent; SO_3 , 34.5 per cent; H_2O , 46.7 per cent.

Physical Properties. *Hardness*, 2. *Specific gravity*, 1.89 to 2.04. *Melting point*, 4.5 to 5 in scale of fusibility. *Index of refraction*, 1.49. *Color*, white to yellowish or pale greenish. *Streak*, white. *Luster*, silky. *Cleavage*, fibrous. *Transparency*, translucent. *Tenacity*, brittle. Readily soluble in water. *Taste*, strongly astringent.

General Description and Mode of Occurrence. Halotrichite usually occurs as silky, fibrous, white, yellowish, or greenish crusts, resembling asbestos but much softer. Its mode of occurrence and origin are similar to those of alunogen.

APJOHNITE

Composition. Apjohnite is a hydrous sulfate of aluminum and manganese, having the formula $\text{MnSO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$: MnSO_4 , 16.3 per cent; $\text{Al}_2(\text{SO}_4)_3$, 37 per cent; H_2O , 46.7 per cent.

Physical Properties. *Hardness*, 1.5. *Specific gravity*, 1.78 to 2.3. *Melting point*, infusible at ordinary temperatures. *Index of refraction*, 1.478 to 1.482. *Color*, white or pale yellowish, greenish, or pinkish. *Streak*, white. *Luster*, silky. *Cleavage*, fibrous. *Transparency*, transparent. *Tenacity*, brittle. Readily soluble in water. *Taste*, astringent, like ordinary alum.

General Description and Mode of Occurrence. Apjohnite is generally found as silky or asbestiform fibrous crusts or efflorescences on the walls of caves or protected rocks. It is usually formed by the action of sulfuric acid, from the decomposition of pyrite or other sulfides, upon shales and other rocks containing alumina and manganese.

KALINITE

Composition. Kalinite is a hydrous double sulfate of potassium and aluminum or a natural potash alum, having the formula $\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$: K_2SO_4 , 18.1 per cent; $\text{Al}_2(\text{SO}_4)_3$, 36.3 per cent; H_2O , 45.6 per cent; or K_2O , 9.9 per cent; Al_2O_3 , 10.8 per cent; SO_3 , 33.7 per cent; H_2O , 45.6 per cent.

Physical Properties. *Hardness*, 2 to 2.5. *Specific gravity*, 1.75. *Melting point*, fuses at 1 in scale of fusibility. *Index of refraction*, 1.430 to 1.458. *Color*, colorless or white. *Streak*, white. *Luster*, vitreous. *Cleavage*, fibrous. *Trans-*

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parency, transparent or translucent. *Tenacity*, brittle. Readily *soluble* in water. *Taste*, strongly astringent.

General Description and Mode of Occurrence. The general description and mode of occurrence are about the same as for alunogen. Its occurrence in commercial quantities is uncommon, but in some instances deposits have been worked.

PICKERINGITE

Pickeringite is a hydrous sulfate of magnesium and aluminum, or a natural magnesium alum, having the formula $\text{MgSO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 22\text{H}_2\text{O}$: MgSO_4 , 14 per cent; $\text{Al}_2(\text{SO}_4)_3$, 39.9 per cent; H_2O , 46.1 per cent. It occurs as white or pale yellowish or reddish fibrous crystals or easily fusible masses. It is of uncommon occurrence. *Hardness*, 1. *Specific gravity*, 1.85.

MENDOZITE

Mendozite is a hydrous sulfate of sodium and aluminum, or a natural soda alum, having the formula $\text{Na}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$: Na_2SO_4 , 15.5 per cent; $\text{Al}_2(\text{SO}_4)_3$, 37.3 per cent; H_2O , 47.2 per cent. Mendozite is an uncommon mineral, resembling ordinary alum, and is found at Mendoza, Argentina, the type locality.

TSCHERMIGITE

Tschermigite is a hydrous sulfate of ammonium and aluminum, or a natural ammonium alum, having the formula $(\text{NH}_4)_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$: $(\text{NH}_4)_2\text{SO}_4$, 14.6 per cent; $\text{Al}_2(\text{SO}_4)_3$, 37.7 per cent; H_2O , 47.7, per cent. Tschermigite is a very uncommon mineral, being found in only a very few places, notably at Tschermig and in a mine near Dux, Bohemia. It is obtained artificially from waste solutions of gas plants.

ALUMINITE

Composition. Aluminite is a hydrous aluminum sulfate, having the formula $\text{Al}_2\text{O}_3 \cdot \text{SO}_3 \cdot 9\text{H}_2\text{O}$: Al_2O_3 , 29.6 per cent; SO_3 , 23.3 per cent; H_2O , 47.1 per cent.

Physical Properties. *Hardness*, 1 to 2. *Specific gravity*, 1.66. *Melting point*, infusible at ordinary temperatures. *Index of refraction*, 1.459 to 1.470. *Color*, white. *Streak*, white. *Luster*, dull or earthy. *Cleavage*, none. *Fracture*, irregular. *Transparency*, opaque. *Tenacity*, brittle. *Feeling*, harsh. *Soluble*, only in acids.

General Description and Mode of Occurrence. Aluminite usually occurs in white, chalky, rounded or irregular masses in beds of clays. Typical localities are at Halle, Germany; and at Brighton, England, in a 3-ft cleft in a chalk bed.

ALUM SHALES SLATES AND CLAYS, OTHER ALUM ROCKS

Many shales, and sometimes slates, contain pyrite and marcasite together with easily alterable alumina minerals. Upon weathering, the sulfides are oxidized, producing sulfuric acid, which attacks the aluminous minerals and forms aluminum sulfate or alums. These alums, being soluble, are carried in solution by slow capillary circulation to the rock surface, where they are either washed away

or, in protected places, deposited in the form of efflorescences or fibrous crusts. Thus, in mine tunnels and workings, particularly in coal mines, these white or light-colored crusts are often found. Sometimes the alums also crystallize in the form of stalactites. In the same way clays containing sulfides may also be sources of the alums. The most common alum minerals of this type are the iron alums and the simple hydrous sulfate of aluminum, but in some cases mine waters deposit sulfates of zinc, copper, cobalt, nickel, and other metals.

The natural weathering in place, of shales, slates, and clays, is usually too slow to produce important quantities of alum, but such materials have been worked commercially in the past, at many places, by accelerating normal weathering. The shales or clays are mined, crushed, and spread out in thin layers to weather; or they are roasted to oxidize the sulfides to the sulfates, finally setting free sulfuric acid, which reacts with the alumina in the shales or clays, forming alum, which may be recovered by solution in water, evaporation, and crystallization.

Potash alum has been made, since the days of Queen Elizabeth, from a hard blue shale near Whitby and Redcar in Yorkshire, England. The aluminum sulfate was extracted from the shale, and a potash salt added in solution. In later times alum has been made in England from coal shales. The production of alum shales in Great Britain from 1910 to 1920 ranged from about 5,000 to 8,000 tons per year, nearly all of which came from the county of York.

The analyses of alum shales in Table 1 are quoted by Merrill.*

TABLE 1. ANALYSES OF ALUM SHALES AND SLATES

	1	2	3	4
Silica.....	65.44	72.40	50.13	51.16
Alumina.....	14.87	16.45	10.73	18.30
Iron oxides.....	1.05	.....	2.27	6.11
Lime.....	0.15	0.17	0.40	2.15
Magnesia.....	1.34	1.48	1.00	0.90
Potash.....	4.59	5.08	.....	Trace
Soda.....	0.48	0.53	.....	Trace
Iron sulfides.....	1.25	2.26	7.53	8.50
Sulfuric acid.....	Undet.	Undet.	Undet.	2.50
Carbon.....	Undet.	Undet.	25.04	{ 8.29
Water.....	Undet.	Undet.		{ 2.00
Total.....	89.17	98.37	97.10	99.91

1. Alum slate from Opsloe, near Christiania, Norway.

2. Alum slate from Bornholm.

3. Alum slate from mine adit at Garnsdorf, near Saafeld, Prussia.

4. Alum shale from Whitby and Redcar district, England.

Alum shales, alum schists, and similar materials occur in large quantities near Whitby, England; Hurlet and Campsie, Scotland; in Thuringia and Westphalia, Germany; in Sweden, Norway, Belgium, and many other places.

In addition to alum shales, slates, and clays, other types of rock may be poten-

* MERRILL, G. P., "The Non-metallic Minerals," 2d ed., pp. 358, 359, John Wiley & Sons, Inc., New York, 1910.

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tial sources of alums, for example, the alum rock from near Gila River, Grant County, N.M., described more fully below. This rock, which is an andesitic breccia, contains soluble salts that deposit alunogen and halotrichite.

Alum from Alunite. Alunite is a hydrous aluminum sulfate that has been an important source of alum. This mineral is treated under Alunite, where the manufacture of alum from alunite is also described.

Typical Occurrences. *United States.* One of the largest reported occurrences of alum minerals in the United States is that described by Hayes* in Grant County, N.M. These deposits occur in a small arid region of igneous rocks, on both sides of Gila River, about 27 miles due north of Silver City, in portions of sections 19, 20, 29, and 30, T.13S, R.13W.

The alum occurs in large masses of highly altered andesitic volcanic breccia, called alum rock by Hayes, surrounded by basalt. There are several such masses, but the largest is roughly circular in shape and about a mile in width. The alum rock is composed of a fine-grained ground mass and was originally composed of minute crystals of plagioclase feldspar embedded in a glassy material. In the less altered and unleached portions very fine, dustlike particles of pyrite are abundant. All the alum rock is highly altered and, where exposed to leaching, is invariably porous. The composition of the various phases of the alum rock is shown in the analyses given by Hayes (see Table 2).

TABLE 2. ANALYSES OF ALUM ROCK FROM GILA RIVER, N.M.
(W. T. Schaller, Analyst)

	1	2	3	4
Soluble in water:				
Al ₂ O ₃ + Fe ₂ O ₃	0.51	0.22		
SO ₃	1.83	1.64		
Insoluble in water:				
SiO ₂	55.76	50.45	57.25	83.51
Al ₂ O ₃ (+TiO ₂).....	20.64	18.61	32.27	5.55
Fe ₂ O ₃ (total iron).....	4.16	3.79	Trace	Trace
Loss on ignition.....	18.07	23.85	12.07	7.38
Ignited residue insoluble in water.....	81.19	76.16	88.00	91.69

1. Alum rock, white, mottled bluish gray, from tunnel 2, 50 ft from mouth of tunnel.
2. Alum rock, disintegrated, from dump of tunnel 2.
3. Alum rock, white, chalky, from point of ridge between forks of Alum Creek.
4. Alum rock, pinkish white, porous, from summit of Alunogen Ridge.

Incrustations of two forms are found, one upon the sides of the cliffs in protected places, and the second upon the sides of tunnels that had been driven in the rock in 1893, some 12 years or more before Hayes's examination.

The first or cliff incrustations are from a few inches to 3 or 4 ft thick and are composed of yellowish-white, cellular or powdery alunogen of the composition given in Table 3.

* See C. W. Hayes, The Gila River Alum Deposits, *U.S. Geol. Survey, Bull.* 315, 1907, pp. 215-223, from whose work this description is taken.

TABLE 3. ANALYSES OF ALUNOGEN FROM GILA RIVER, N.M.

	1	2	3
Al ₂ O ₃	16.29	15.52	15.3
SO ₃	36.93	34.43	36.0
H ₂ O.....	46.45	45.56	48.7
Insoluble residue.....	.....	7.62	
	99.67	100.13	100.0

1. Analyst, George H. Corey, carefully selected crystals.

2. Analyst, F. W. Clarke, Pinkish Crusts, *U.S. Geol. Survey, Bull.* 9, 1884, p. 13.

3. Theoretical composition of alunogen: Al₂(SO₄)₃ + 18H₂O.

The second or tunnel incrustations were 3 to 6 in. thick and consisted of very pale, greenish, silky, fibrous crusts of halotrichite, which had apparently grown in annual increments of $\frac{1}{3}$ to $\frac{1}{2}$ in. per year. This material was of the composition given in Table 4.

TABLE 4. ANALYSES OF HALOTRICHITE FROM GILA RIVER, N.M.

	1	2	3
FeO.....	7.94	13.50	7.8
Al ₂ O ₃	11.77	7.27	11.0
SO ₃	35.25	37.19	34.5
H ₂ O.....	45.09	40.62	46.7
Insoluble.....	.....	0.50	
	100.05	99.17	100

1. Analyst, W. T. Schaller, carefully selected fibrous crystals from tunnel 2.

2. Analyst, F. W. Clarke, Fibrous Mineral of Silky Luster, *U.S. Geol. Survey, Bull.* 9, 1884. Contains a trace of Fe₂O₃.

3. Theoretical composition of halotrichite: FeSO₄ + Al₂(SO₄)₃ + 24H₂O.

Several hundreds or even thousands of tons of the alum incrustations are evidently available, but the main possible source of commercial alum must be the very large quantities of relatively low-grade alum rock. This may be of some future commercial importance if the difficulties of transportation, mining, and extraction can be successfully overcome.

*Nevada.** A deposit of the natural potash alum, kalinite, occurs in Esmeralda County, about 35 miles west of Tonopah, 10 miles north of Silver Peak, and about 6 miles south of the Tonopah & Goldfield Railroad.

The alum is associated with native sulfur in rhyolite, which occurs in elongated dike-like or neck-like masses, apparently intrusive into Tertiary sedimentary rhyolitic tuffs. The alum occurs in an irregular network of veins, some of which are several inches thick, which split and ramify through the broken masses of altered rhyolite. The largest rhyolite "neck" is about 200 ft in diameter. The

* See J. E. Spurr, Alum Deposit near Silver Peak, Esmeralda County, Nevada, *U.S. Geol. Survey, Bull.* 225, 1904, pp. 501-502. Also Lindsay, Duncan: Recovery of Potash Alum and Sulphur at Tonopah, *Chem. Met. Eng.*, Vol. 24, No. 12, pp. 529-530, Mar. 23, 1921.

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rhyolite is easily friable and itself contains a large per cent of disseminated alum. When exposed to the air, the alum rapidly dehydrates and crumbles to a white powder, so that it is not conspicuous in the outcrop, and the amount actually present can only be seen on fresh fractures.

This deposit was originally prospected for sulfur but was not developed. Years ago it was acquired by Western Chemicals, Inc., of Tonopah, Nev., and a plant installed for the recovery of both the alum and the sulfur. Duncan* states that more than 100,000 tons of ore have been already blocked out and that the estimated probable tonnage is over 1 million tons. The run-of-mine ore has the following analysis:

	<i>Per Cent</i>
Kalinite [$K_2Al_2(SO_4)_4 \cdot 24H_2O$].....	20.0
Sulfur (S), free.....	15.0
Silica (SiO_2).....	58.8
Alumina (Al_2O_3).....	2.6
Calcium sulfate ($CaSO_4$).....	2.1
Calcium carbonate ($CaCO_3$).....	1.2
Iron oxide (Fe_2O_3).....	0.3
Total.....	100.0

A plant with a daily capacity of 10 tons of chemically pure alum was reported to have operated with this raw material from 1920 to 1923.

Colorado. Kalinite has been reported as efflorescences of no commercial importance at several places in Jefferson and Larimer counties. Pickeringite has been found near Colorado City, and halotrichite occurs at several coal mines in Boulder County and elsewhere. Alunogen is found at Doughty Springs and Alum Gulch.

Tennessee. Apjohnite occurs associated with epsomite and melanterite ($FeSO_4 \cdot 7H_2O$) in the so-called Alum Cave of Sevier County at the headwaters of the Little Pigeon, a tributary of the Tennessee River. It occurs in silky transparent needles and thick masses on the protected sides of an overhanging cliff 80 to 100 ft high.

China. Natural alums are found in China in the provinces of Anhwei, Yunnan, and Chekiang. In the first two provinces it is extracted only for native use and none is exported; but alum from Chekiang Province is exported in considerable quantities, chiefly from the port of Shanghai, but to some extent from Wenchow.

Uses. The chief uses of alum are as a mordant in dyeing; in sizing paper; in tanning skins; and in clarifying water, sewage, and other turbid liquids. It is also used in making lake colors; for hardening plaster casts; in medicine; and as an ingredient of some baking powders. In ore dressing it is used to coagulate and settle slimes and other water suspensions of very fine particles prior to filtering.

It should be noted that for many uses aluminum sulfate, known commercially as "concentrated alum," is used in place of the true alums.

* DUNCAN, LINDSAY, *op. cit.*

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ALUMINUM SILICATES

Andalusite, Kyanite, Sillimanite, Dumortierite, and Mullite

The aluminum silicates and their combinations comprise an extensive group of minerals. Sericite, pinite, pyrophyllite, topaz, and kaolin have been described in other chapters. This group has been referred to commonly as the sillimanite group of minerals due to the erroneous belief that andalusite and kyanite, the first simple aluminum silicates to become commercially important, inverted upon heating to sillimanite. Further research proved that this product actually was mullite with a different ratio of alumina to silica. The commercialization of these minerals was due to the search for an improved porcelain for spark plugs for use in airplane motors developed in the First World War. Previous to this time the aluminum silicates listed in the title were little more than museum curiosities.

The common properties of these minerals are shown in Table 1.

ANDALUSITE

Composition. Andalusite is aluminum silicate, Al_2SiO_5 or $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$: Al_2O_3 , 62.93 per cent; SiO_2 , 37.07 per cent. Samples exhibiting pure composition are rarely encountered. Its composition is the same as sillimanite and kyanite.

General Description. Andalusite occurs as large, rough, nearly square gray or reddish prismatic crystals, or sometimes in very tough, columnar or granular masses. *Chiastolite* is an impure soft variety occurring in rounded prisms, any cross section of which shows a cross due to the regular arrangement of the particles of dark (usually organic) impurities.

Physical Properties. *Color*, varies from light to dark gray, red, green, bluish, or white. *Streak*, white. *Luster*, vitreous to dull. *Cleavage*, imperfect prismatic. *Fracture*, uneven. *Transparency*, transparent to opaque. *Tenacity*, brittle. Insoluble in acids.

Occurrence. Andalusite usually occurs in metamorphic rocks, especially in gneisses, schists, and slates; also occasionally in granite.

Common mineral associates are kyanite, sillimanite, corundum, mica, garnet,

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and tourmaline, also quartz and, more rarely, rutile, lazulite, pyrophyllite, and pyrite. Most commonly it occurs as disseminated crystals in gneiss or schist, but sometimes it is found in large, nearly pure, masses of coarsely granular structure.

TABLE 1. PHYSICAL PROPERTIES OF COMMON ALUMINUM SILICATES

	Hard- ness	Specific gravity	Crystal system	Indexes	Volume expan- sion, per cent	Decomposition temperature, °C
Andalusite . . .	7.5	3.16-3.20	Ortho.	1.634 1.643 1.639	5	1380-1400
Kyanite	5-7	3.56-3.66	Tri.	1.712 1.728 1.720	16	1350-1380
Sillimanite . . .	6-7	3.23	Ortho.	1.659 1.680 1.660	6	1540-1550
Dumortierite .	7	3.30	Ortho.	1.678 1.689 1.686	Expands	1250
Mullite	6-7	3.23	Ortho.	1.638 1.653 1.642	..	1810 to liquid and Al ₂ O ₃

Andalusite in relatively small quantities is found in many localities, of which the following are often noted: Westford, Lancaster (chiastolite variety), and Sterling, Mass.; Litchfield and Washington, Conn.; Standish, Maine; Minas Geraes, Brazil; Lizens, Tyrol; and Andalusia, Spain.

Large masses of andalusite, sufficiently extensive to be commercial sources, are very rare.

The largest commercially productive deposit is located on the west slope of White Mountain, Mono County, Calif., at an elevation approaching 10,000 ft. It is controlled by the Champion Spark Plug Co. of Detroit, Mich. The rock is described as a fairly pure andalusite associated with small amounts of other minerals.²² The ore body is irregular and the andalusite is hand-picked with care to produce a shipping grade containing over 90 per cent. Grade is controlled by determination of specific gravity and desired material is selected with a gravity of between 3.01 and 3.06. While a large quartz mass has been found to contain andalusite, relatively small areas possess enough to justify mining. Associated

minerals consist of pyrite and pyrrhotite, muscovite corundum, rutile, lazulite, and pyrophyllite.

The crude material is shipped to Detroit, where it is crushed and passed over a magnetic separator. Coarse material, varying in size from 8 to 30 mesh, is prepared for refractories. Finer material, 60 per cent through 325 mesh, is produced by grinding in a pebble mill for use in porcelain and whiteware bodies.

Andalusite also has been produced in Nevada near Hawthorne, Mineral County, and in other areas in California. Andalusite sands have been reported in Western Transvaal, Africa. Sales of 450 tons were reported in 1939.

KYANITE

Composition. Kyanite (sometimes spelled "cyanite"), or disthene, is aluminum silicate, Al_2SiO_5 : Al_2O_3 , 62.93 per cent; SiO_2 , 37.07 per cent.

General Description. Kyanite usually occurs in long-bladed, triclinic blue crystals or fibrous masses, often in radial aggregates.

Physical Properties. *Color*, usually some shade of blue, hence the name. *Streak*, white. *Luster*, vitreous. *Cleavage*, good in three directions. *Transparency*, translucent to transparent. *Tenacity*, brittle.

Occurrence. Kyanite is a metamorphic mineral and occurs chiefly in gneisses and schists, often associated with corundum, andalusite, staurolite, garnet, and rutile. It is found in the corundum localities of Gaston, Rutherford, and Yancey counties, N.C.; Chester, Mass.; Chester and Delaware counties, Pa.; Litchfield and Washington, Conn.; also in the St. Gothard district, Switzerland, in the Tyrol; near Wheatland, Wyo.; in Alabama; and in many other localities. Commercial production in the United States has been active near Ogilby, Calif.; Baker Mountain, Va.; Burnsville, N.C.; and Clarksville, Ga. Since the kyanite is found in schists closely associated with undesirable minerals, mechanical separation must be employed to make a product sufficiently pure for industrial use. Many processes are employed, depending upon local conditions. In general the rock is crushed, ground, and classified. It then may be concentrated by flotation or by gravity methods and cleaned by magnetic separation. The final product may be calcined or not before shipment. At Clarksville, Ga., kyanite weathered from schists has formed surface deposits. These have been washed, screened, and jigged. The Ogilby, Calif., rock has been treated by an ingenious system of calcining and sudden cooling that shatters the associated quartz. The material is then crushed and screened. The long kyanite fibers collect on the screen while the quartz sand passes through.

Foreign kyanite has become important in American industry. The principal source is India. In recent years tonnage has been received from British East Africa and the Union of South Africa. The Indian kyanite is a massive, fine-grained type. It is found in boulders that have weathered from the original lode and been subjected to some transportation as they are rounded. They are found in Singhbhum district at Lapsa Bum, about 100 miles west of Calcutta. Some topaz has been reported in the same area. Production to date is from these detrital boulders. A massive form of kyanite is present, sometimes containing

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as high as 85 per cent corundum. Indian kyanite exhibits a low expansion and produces a hard grog with a high constancy of volume.

Imports are shown in Table 2.

TABLE 2. CONSUMPTION AND STOCKS OF IMPORTED KYANITE IN THE UNITED STATES, 1948

	Short tons	Value	Consumption, short tons	Stocks Dec. 31, short tons
Australia.....	1,619	\$23,861		
British East Africa.....	8,108	105,676		
India.....	6,823	122,544		
Mozambique.....	203	2,098		
Union of South Africa.....	338	4,876		
	17,091	259,055	11,770	5,538

SILLIMANITE

Composition. Sillimanite (fibrolite) is aluminum silicate, Al_2SiO_5 or $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$. Al_2O_3 , 62.93 per cent; SiO_2 , 37.07 per cent.

General Description. Sillimanite usually occurs as long, thin, needlelike crystals or in radiating, fibrous or columnar masses. Crystals are often bent and interlaced.

Physical Properties. *Color*, gray, brown, yellowish, or greenish. *Streak*, white. *Luster*, vitreous to silky. *Cleavage*, parallel to brachypinacoidal. *Fracture*, irregular. *Transparency*, transparent to translucent. *Tenacity*, tough. *Insoluble* in acids.

Occurrence. Sillimanite usually occurs as an accessory constituent of gneisses, schists, quartzite sand, and other metamorphic rocks, sometimes associated with andalusite, zircon, or corundum.

Some of the type localities for sillimanite are: Norwich and Willimantic, Conn.; Worcester, Mass.; Westchester and Monroe counties, N.Y.; Chester, Pa.; Freiberg, Saxony; Minas Geraes, Brazil; and Bodenmais, Bavaria.

Small tonnages have been found in South Dakota. Sillimanite occurs in schists in the United States that have not become commercial sources. The largest resources are believed to be in India.¹⁴ Three workable deposits are reported to exist. A massive deposit associated with corundum is located near Sonapahar in Nongstoin State in Assam. The material is reported to be of good grade, and some tonnage of loose sillimanite is available. Due to the inaccessibility of the area no production has been made. Massive sillimanite also associated with corundum has been found in an area 600 by 200 ft on a ridge $\frac{1}{2}$ mile from the village of Pipra in the southeast corner of Rewa State, Central India. A small tonnage is known to exist near Pohra in the Bhandara district in the Central Provinces.

To date, sillimanite has not been important in industry, since it has not been

found in accessible places in large tonnages. Improvements in transportation in India might furnish industrial tonnage.

DUMORTIERITE

Composition. Dumortierite is a silicate of aluminum containing some boron and water. It is represented by the formula $\text{Al}_8\text{BSi}_3\text{O}_{19}$ or $4\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ plus B and OH.

General Description. Dumortierite has been found in dikelike masses and in fibrous or columnar aggregates. The pure mineral has been found in boulders of unknown origin. A dumortierite-rich schist has become the chief source of tonnage.

Physical Properties. *Color*, deep smalt blue to greenish blue. The schists are characteristically pink. *Streak*, white. *Luster*, vitreous. *Transparency*, transparent to translucent.

Occurrence. Dumortierite was first found near Lyon, France. It has been identified in Manhattan, N.Y.; in Arizona, north of Yuma; and in Norway, Brazil, and Madagascar. The schists near Oreana, Nev., have become the most important producing areas.

The deposits of dumortierite are located in the Humboldt Queen Canyon, near Oreana, Nev. The mineral was found first in veinlets in a dike of andalusite and quartz. Boulders of large size were found, and subsequent mining led to the discovery of a massive, schistose mineral occurring in a lens. Color varied from light to dark pink. According to Peck¹⁶ the composition of the rock is as follows:

	<i>Per Cent</i>
Dumortierite.....	75.33
Muscovite.....	14.16
Excess silica.....	8.53
Other minerals.....	1.98
	<hr/> 100.00

The dumortierite is shipped to Detroit, Mich., where it is prepared for use in the manufacture of spark-plug porcelains in the same manner that andalusite is treated. It burns to a pure white and converts to mullite at a lower temperature than the other aluminum silicates.

MULLITE

Composition. Mullite has the composition $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$.

Occurrence. Mullite was recognized in porcelains as a conversion product of various aluminum silicates before it was found in nature. The only natural occurrence is on the island of Mull in the Western Isles of Scotland. It is found as inclusions where aluminous sediments have been entrapped by igneous rocks. The natural mineral has no commercial significance.

Artificial mullite has been manufactured by a number of processes. Various alumina-silica mixtures in proper proportion have been employed. The materials are finely ground, briquetted, and converted to mullite by firing in a furnace at a high temperature. During the war it was reported that Germany was

forced to produce manufactured mullite to replace kyanite previously obtained from India.¹⁰ Mullite was produced, but at an expense estimated to be three times that of the natural kyanite. A mixture of clay, aluminum hydroxide, fused alumina, and feldspar was prepared and fired in a tunnel kiln to a maximum temperature of 1600°C. The addition of a small amount of ground Indian kyanite appeared to serve as a nucleus and improved crystallization. The total tonnage produced is unknown but is believed to be small.

PRODUCTION AND UTILIZATION OF ALUMINUM SILICATES

Production. The tonnage of the aluminum silicates produced annually in the United States is not known accurately. Much of the production is consumed directly by the owners of the mines who operate them for their own requirements. The total is not large, probably between 10,000 and 20,000 tons. A large proportion of the total is kyanite.

Utilization. The utilization of the aluminum silicates is dependent upon conversion to mullite when fired to the proper point. The interlacing mullite crystals produce a body of great strength and refractoriness. Such material does not spall, stands the shock of heating and cooling well, and is resistant to slag erosion. Such ceramic bodies are particularly valuable in spark plugs, laboratory ware, saggers, kiln furniture, glass tank blocks, and other special refractories.

Prices. Kyanite is the only mineral sold freely on the market in quantities sufficient to establish a price. In 1950 kyanite was quoted at \$26 per ton fob Virginia in bulk, and at \$29 per ton in bags for 35-mesh material. Kyanite, 200 mesh, was quoted at \$37 per ton. Imported material cif Atlantic ports was quoted at \$30 per ton. All prices for carload lots.

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ALUNITE (ALUM STONE)

Composition. Alunite, a hydrous sulfate of potassium and aluminum, $K(AlOH)_3(SO_4)_2 \cdot 3H_2O$, or $K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$: Al_2O_3 , 37.0 per cent; K_2O , 11.4 per cent; SO_3 , 38.6 per cent; H_2O , 13.0 per cent. Sodium often replaces part of the potassium. Analyses of typical alunites are given in the accompanying table.

ANALYSES OF ALUNITE

	1	2	3	4	5	6
K_2O	9.71	7.55	9.64	9.51	6.53	10.35
Na_2O	0.56	.....	.....	1.12	0.82	0.89
Al_2O_3	34.40	27.60	37.98	37.52	25.91	35.53
Fe_2O_3	Trace	1.20	.....	0.26	0.07	0.34
SiO_2	5.28	22.71	.....	1.92	32.40	1.13
SO_3	36.54	29.74	34.77	36.76	24.47	35.61
P_2O_5	0.50	.....	.....	Trace	0.02	0.23
H_2O	13.19	11.20	17.61	13.25	9.81	15.50
Miscellaneous.....	.....	.....	.....	.....	0.07	0.72
Total.....	100.18	100.00	100.00	100.34	100.10	100.30

1. Marysvale, Utah; W. T. Schaller, analyst, *U.S. Geol. Survey, Bull.* 511, p. 8.
2. La Tolfa, Italy; analysts quoted by S. J. Johnstone, "Potash," p. 55. Imperial Institute, London, 1922.
3. Calafatite variety from Benahadux, Spain; analysis from Johnstone, *op. cit.*
4. Pink variety, Bulladelah, New South Wales; analysis from Johnstone, *op. cit.*, p. 54.
5. Purple variety, Bulladelah, New South Wales; analysis from Johnstone, *op. cit.*, p. 54.
6. Carrickalinga, South Australia; analysis from Johnstone, *op. cit.*, p. 54.

General Description. Alunite occurs as a white or light-colored, compact, fibrous or finely granular rock, often somewhat resembling a dull limestone; also as tabular or nearly cubic rhombohedral crystals; also intermixed with siliceous material forming a compact, hard, granular, nearly white rock.

Physical Properties. *Hardness*, 3.5 to 4. *Specific gravity*, 2.58 to 2.8. *Melting point*, infusible but decrepitates. *Index of refraction*, 1.572 to 1.592. *Color*, white, yellowish, grayish, reddish, or colorless. *Streak*, white. *Luster*, vitreous; pearly on cleavage edges. *Cleavage*, massive none; in crystals perfect basal. *Fracture*, conchoidal, earthy, or splintery. *Transparency*, transparent to nearly opaque. *Tenacity*, brittle when pure to tough when intermixed with silica.

Occurrence and Distribution. Alunite is a fairly common mineral and is widely disseminated through many volcanic rocks. It is also found in small percentages in clays. Concentrations of purity and size sufficiently large to be of commercial interest are comparatively rare. The mineral has been produced at La Tolfa, Italy, where production from 5,000 to 8,000 tons per year has been reported; and near Bullahdelah, New South Wales, where production up to 25,000 tons per year was recorded during the potash shortage incident to the First World War. Occurrences are known in Spain, France, Hungary, Greece, Western Australia, and the Transcaucasia of the U.S.S.R. In the United States occurrences are known in Arizona, California, Colorado, Nevada, Utah, Washington, and Texas. According to Thoenen¹³ the first six states contain at least one deposit of commercial interest.

Alunite in Utah. The alunite deposits in Utah are the largest known in the United States. They have been the most important producers. Industrial interest in their exploitation has been acute in two periods: in the First World War, when they were used as a source of potash, and in the Second World War, when they were employed as a source of alumina. Two geologic types of deposit are recognized. Vein deposits are believed to be the product of deposition from ascending solutions of magmatic origin. Replacement deposits, mostly confined to volcanic rocks, appear to be the result of reaction between ascending solutions and the wall rock, with a variable replacement of the latter by alunite. The vein deposits are found in Alunite Ridge between the forks of Cottonwood Creek, about 7 miles from Marysvale. The replacement deposits are greater in number and more extensive in area. They occur in an area surrounding Marysvale, most of the mineralization of this type being in the Antelope Range. During the First World War a large but indefinitely known tonnage was mined from the vein deposits. The tonnage is thought to have exceeded one-quarter of a million tons. Accurate figures are not available. Estimation of reserve tonnage is difficult, due to the irregularity of the alunite-bearing formations, ignorance of the total number of veins present, and inability to determine the lower limit of alunite content that can be employed in any process of commercial interest. Thoenen¹³ estimated that the tonnage of pure alunite as calculated from the content of alunitized rock was equivalent to over 11,000,000 tons.

Utilization. Pure alunite is insoluble in water and in common acids, but if it is calcined to 500°C it loses its water of hydration, and the residue consists largely of anhydrous potash alum, part of which is readily soluble in water or acids. However, if the heat is increased beyond 500°C, most of the sulfur combined with the alumina is released as oxides and the residue consists of potassium sulfate and alumina. Thus may be made either potash alum (and aluminum sulfate) or potassium sulfate and alumina. In the latter case sulfuric acid might also be made as a by-product. The extraction of potash from alunite is described under Potash Salts.

The following descriptions of the recovery of alum from alunite are quoted from Loughlin,* who quotes from various sources as noted:

* LOUGHLIN, G. F., Recent Alunite Developments near Marysvale and Beaver, Utah, *U.S. Geol. Survey, Bull.* 620, 1916, pp. 267-270.

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The description of the ancient process of manufacturing potash alum from alunite in foreign countries, which was reviewed by Butler and Gale,* is here repeated for the reader's convenience.

"A considerable amount of alum is prepared from alunite. Alunite contains the elements of potassium alum, basic aluminum sulfate and free alumina. In Sicily it is made into heaps and calcined in the open air. At Tolfa, where the manufacture is carried out on a larger scale, the roasting is conducted in furnacelike limekilns lined with refractory materials. The mineral is heated in large pieces by the flame without direct contact with the fuel until sulfur dioxide begins to escape. The calcination requires about 6 hours, the mass losing about 35 per cent of water. During the ignition the excess of alumina beyond that necessary to produce alum is rendered insoluble and no longer has the property of precipitating basic sulfates from the solution. The calcined mass is exposed to the air upon a clay floor for some weeks, during which time it is occasionally moistened. The mudlike product is agitated in boilers with water at 70°C, and the clear decanted liquid, of density 10 to 12°Bé, is evaporated to 32°Bé and crystallized in small wooden tubs. The crystals are cubic, opaque, and reddish from the presence of ferric oxide. This iron is, however, quite insoluble and may be separated by recrystallization; the soluble iron is said to be less than 0.005 per cent. In this way 'Roman alum' was formerly largely produced. On account of their great purity, the red crystals were much sought after.

"Alunite is now largely converted into alum by treatment with sulfuric acid and addition of potassium sulfate. Guyot† has examined this process and recommends the following method:

"On ignition of alunite the free alumina is first rendered anhydrous and soluble in sulfuric acid; at a higher temperature the basic sulfates become soluble, but if the temperature be allowed to rise too high the alumina becomes vitrified and is insoluble. Guyot recommends ignition at 800°C for 3 hr as the best means of rendering the maximum of both these substances soluble. The composition of the calcined mass is determined, and acid is used in proportion to the amount of soluble sulfate contained. For a product of the following composition: K_2SO_4 , 14 per cent; $Al_2O_3 \cdot 3SO_3$ (present as alum), 26.55; $Al_2O_3 \cdot 3SO_3$ (free), 6.56; Al_2O_3 (free), 18.58; H_2O , 11.90; Fe_2O_3 , 0.80; siliceous residue, 21.61 per cent, the proportions given below would be most satisfactory. Into a clay oven is poured 12.5 tons of sulfuric acid of 52°Bé diluted to 30°Bé and heated to 80 or 90°C. Eight tons of the calcined mineral is then added in portions and well stirred. After the whole has been added, the liquid is left for 2 hr, then evaporated to 38°Bé and treated with 2.7 tons potassium sulfate. The process up to this point occupies 10 hr; after a further period of 13 hr the clear liquid is decanted off; its density should not exceed 42°Bé. The muddy liquid remaining is reduced to 24°Bé by the addition of mother liquor from a previous crystallization, stirred, allowed to settle, drawn off clear, mixed with the first decantate, and crystallized in a vat. After one day the crystals are removed, redissolved, and recrystallized. The muddy residue is crystallized out for a further crop of alum. The total yield of alum is about 2.3 times the original weight of ore. The insoluble matter contains 3 per cent alumina and 2.01 per cent potassium sulfate, in addition to silica, etc.

* *U.S. Geol. Survey, Bull.* 511, pp. 59-60; quoted from T. E. Thorpe, "Dictionary of Applied Chemistry," London, 1890, p. 78.

† GUYOT, M. P., Sur la richesse industrielle de l'alunite crue, en poudre, *Paris acad. sci. compt. rend.*, Vol. 95, pp. 693, 694; Expériences sur la calcination de l'alunite en poudre, destinée à la fabrication de l'alum et du sulfate d'alumine, *Idem*, pp. 1001-1003.

"According to C. Schwartz,* the best temperature for the roasting is 500°C, and the acid used should have a density between 1.297 and 1.530."

The summary concerning the utilization of the Australian deposit at Bullahdelah is contained in the following paragraphs.†

"The following is a process by which alum is manufactured from alunite: The mineral is ground and then calcined in reverberatory furnaces to dehydrate it and drive off part of the SO_3 . It is next treated with a weak solution of sulfuric acid in lead-lined tanks, heated to boiling point by steam jets. The liquor is allowed to settle in the same vats, and the clear solution is run off into crystallizing tanks, which are kept in constant agitation while cooling, the alum crystallizing out and sulfate of alumina remaining in solution. The residue in the vat is boiled again with water, and the solution run off again in the same way. The liquor containing sulfate of alumina is then returned to the vats, and sufficient of the calcined mineral added to neutralize completely any free acid. It is then heated to the boiling point and ebullition continued until partial reversion takes place, the reversion being accompanied by a precipitation of the hydrated ferric oxide.

"The alum, after collection, is washed and then refined in vats, similar to but deeper than those originally employed, and the concentrated solution is run into roaching tuns in which it is crystallized; it is then broken up and packed ready for the market.

"The sulfate of alumina solution, after all the alum has been crystallized from it, is concentrated in small vats heated with steam coils, and the lower qualities of sulfate of alumina are formed by running the liquor onto lead tables and breaking the solidified material into blocks, the higher qualities (containing over 17 per cent of soluble alumina) being cast on copper trays. These higher qualities, which vary in color from yellow to green in the slabs, are then ground in a disintegrator, and the material assumes a snow-white appearance.

"It is, of course, feasible, by the addition of K_2SO_4 , to convert the whole of the alumina contained in the stone into alum if desired, but the more profitable method of treatment, when the better classes of sulfate of alumina can be sold at standard prices, is to make only so much alum as there is sulfate of potash present in the stone to produce, and convert the rest of the alumina into soluble sulfate of alumina (of commerce).

"Sulfur may be obtained by distilling the mineral in the presence of any reducing gas like coal gas. Sulfuric acid may also be distilled from the mineral. Heating with carbonate of baryta produces aluminate of potash."

During its brief existence as a source of potash alunite in Utah was crushed, calcined, and leached with water, the soluble potassium sulfate being recovered from the solution. The Kalunite process³ employed modern chemical engineering techniques, allowing the recovery of potash and alumina. This process involved conversion of the alunite into potash alum by dehydration and solution of the product in dilute sulfuric acid and potassium sulfate solutions. This alum was autoclaved to a hydrous basic potassium aluminum sulfate. This was calcined, driving off sulfur oxides, and leaving a mixture of alumina and potassium sulfate. The soluble potassium sulfate is readily separated from the

* Über die Aufschliessung des Römischen Alunits, *Deutsch. chem. Ges. Ber.*, Vol. 17, p. 2887.

† PITTMAN, E. P., Alunite or Alumstone in New South Wales, *New South Wales Geol. Survey, Rept.*, 1901, pp. 419-429.

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insoluble alumina, producing two marketable products. The many complex economic factors controlling the markets for these commodities have increased the difficulties encountered in establishing an industry based on alunite.

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ANHYDRITE

Composition. Anhydrite is a sulfate of lime represented by the formula CaSO_4 ; CaO, 41.2 per cent; SO_3 , 58.8 per cent.

General Description. Anhydrite usually occurs in large massive aggregates, marblelike or sugarlike in texture, in which quarries of great size may be developed. It also is found in fibrous masses, and rarely as prismatic, orthorhombic crystals. It is not stable and absorbs water, combining with it to form gypsum. This is accompanied by a large increase in volume.

Physical Properties. *Hardness*, 3 to 3.5. *Specific gravity*, 2.7 to 3.0. *Melting point*, 3 in scale of fusibility. *Color*, white, gray, at times containing coloring agents that produce bluish, reddish, and black effects. *Streak*, white. *Cleavage*, in three directions at right angles. *Fracture*, irregular. *Transparency*, transparent to opaque. *Tenacity*, brittle. *Index of refraction*, 1.571 to 1.614.

Occurrence. Anhydrite is a frequent associate of gypsum and rock salt, all these minerals being the products of evaporation of bodies of water. There is strong geologic evidence that many deposits of gypsum were originally precipitated as anhydrite. The gypsum has been produced by the gradual absorption of water and hydration of the anhydrite. This reaction takes place most readily at shallow depths where expansion in volume is possible. Therefore, it is not an infrequent event that the amount of anhydrite in a gypsum deposit will increase with depth and at times become so dominant as to cause the abandonment of the operation as a gypsum producer. The presence of large irregular masses of anhydrite surrounded by gypsum has similarly become objectionable in gypsum quarries. Anhydrite is found in large tonnages in Nova Scotia, Cape Breton Island, and New Brunswick in Canada. It is a common associate of gypsum in New York, Michigan, and Kansas.

Uses. Some varieties have been cut and polished for ornamental purposes. The tonnage involved has not been important. Its lack of stability precludes its use as a building stone. Its high sulfur trioxide content and the absence of water have made it useful where calcium sulfate as pure as possible has been in demand. Large tonnages of gypsum-anhydrite mixtures with an anhydrite content varying from 30 to 50 per cent have been used satisfactorily as a retarder by the manufacturers of portland cement. It is also used extensively as a fertilizer for certain crops of the legume family such as the peanut. The growing importance of this crop for the production of edible oil has developed a substantial market for anhydrite. This is shipped as an anhydrite-gypsum mixture, in which anhydrite is the principal mineral. It is shipped from Canadian ports and moves largely to Norfolk, Va., for distribution to the peanut belt of the south.

Anhydrite has not been used as the basis of a chemical industry in the United States, in part because other sources of sulfur are too highly developed and easily reached. In England, Germany, and France it has been employed in such a manner. It has been used in the manufacture of ammonium sulfate, sulfuric acid, and cement.

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APATITE

Composition. Apatite is a phosphate of lime containing varying amounts of chlorine, fluorine, and hydroxyl. It is represented by the formula $\text{Ca}_5(\text{F}\cdot\text{Cl})\text{-(PO}_4)_3$. The phosphorus pentoxide content varies from 41 to 42 per cent. Fluorine content may reach 3.8 per cent; generally, it is about 3.3 per cent.

General Description. The mineral occurs at times in well-formed hexagonal crystals. Some of these, particularly those found in pegmatites, may be transparent and lilac, green or purple in color. Such material is cut as a gem, although it is too soft to wear permanently. It also occurs as a common rock constituent in irregular grains, and in massive form it supplies the bulk of the world's greatest source of phosphorus, phosphate rock.

Physical Properties. *Hardness*, 5. *Specific gravity*, 3.1 to 3.2. *Melting point*, 5 in scale of fusibility. *Color*, green, brown, yellow, gray, red, violet, or colorless. *Streak*, white. *Luster*, vitreous to greasy. *Cleavage*, imperfect, basal, conchoidal fracture. *Transparency*, transparent to opaque. *Tenacity*, brittle. *Index of refraction*, 1.631 to 1.634.

Occurrence. Apatite is a common mineral, appearing in small amounts in all igneous rocks. Clarke and Washington classify it as one-tenth in abundance among the minerals that compose the igneous rocks, being exceeded in quantity only by the common rock-forming minerals. Concentrations rich enough to justify mining are found in a few localities.

Apatite mining was a substantial industry in Canada from 1883 to 1891, with an annual output averaging about 25,000 tons. The mineral was produced first in Renfrew County, Ontario, and later in Ottawa County, Quebec, which became the leading producer.² The mineral occurs in irregular deposits associated with phlogopite mica, pyroxene, and calcite. The discovery of large tonnages of easily recovered phosphate rock in the United States and other areas resulted in the suspension of mining. Erratic production in small amounts as a by-product of mica mining has been recorded at times. A large reserve tonnage of apatite is believed to exist.

Apatite is a conspicuous constituent of the nelsonite dikes, an unusual association of ilmenite, apatite, and rutile, that are found near Piney River in Nelson County and, to a lesser extent, in Amherst County, Va.⁵ Ores taken from these sources are sources of phosphorus and titanium. After separation from its mineral associates the apatite exhibits high purity. Analysis shows: P_2O_5 , 40.88 per cent; CaO , 53.94 per cent; and F_2 , 3.61 per cent. Its economic recovery is facilitated by the fact that the titanium minerals present are also of value. The apatite is processed and sold as monocalcium phosphate. Total reserves of known and suspected ores are believed to be large.

The industrial significance of apatite has been altered completely by the discovery and exploitation of large deposits in Russia. They are located in the Kola peninsula within the Arctic Circle. The mineral is found with nepheline. An upper ore body composed of 80 per cent apatite and 20 per cent nepheline and averaging 30.8 per cent P_2O_5 is reported. This is accompanied by a lower

zone containing more nepheline and a much lower P_2O_5 content. Reserves of 2 billion tons are said to exist. The rapid development of this occurrence by the Russian government converted it to a major producer. The neighboring city of Kirovsk grew from a hamlet to a city with a population of 40,000 people within a short time. The absence of phosphate rock, conveniently located, necessitated the opening of this area. Large deposits of apatite have been developed in Norway, on the southern coast between Langesund and Arendal.

Utilization. Apatite is used for the manufacture of phosphoric acid and phosphates. It is also employed in the production of commercial fertilizers for soil improvement. In North America its use in the fertilizer market has been supplanted by the cheaper and more easily processed phosphate rock. It may become a commercial source of fluorine.

Synthetic hydroxyapatite has been developed at Mellon Institute in making a new granular adsorbent, called Synthad, as a superior substitute for natural bone char in sugar refining.*

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ASBESTOS

Definition. The term "asbestos," as now used, is not the name of a distinct mineral, but is a commercial term applied to any mineral that can be readily separated into more or less flexible fibers. The original asbestos was a variety of amphibole, of little present importance, but now there are several important varieties of asbestos, of which chrysotile is in most common use.

Varieties of Asbestos and Their Properties. *Chrysotile* is a fibrous form of serpentine, with which it is always associated. It is a hydrous magnesium silicate, represented by the empirical formula $H_3Mg_3Si_2O_{10}$, and contains 12.9 per cent of water of composition. It occurs in aggregates of fine, crystalline silky

* Annual Rept. Mellon Institute for 1948, *Chem. Eng. News*, Vol. 27, No. 22, p. 1594, May 30, 1949.

fibers, which are flexible and have considerable tensile strength. These fibers usually range in length from less than $\frac{1}{8}$ to 1 or $1\frac{1}{2}$ in., but fibers as long as 5 to 6 in. are sometimes found, and an extreme length of 24 in. has been noted.¹⁴ Chrysotile fibers are nearly always brilliant white, but aggregates of fibers may vary from white and pink, through yellowish and yellowish green to olive-green. *Hardness*, 3 to 3.5. *Specific gravity*, 2.2 to 2.3. *Luster*, subresinous to greasy, pearly and silky.

Crocidolite is a soda-iron, monoclinic amphibole, having the formula $\text{NaFe}(\text{SiO}_3)_2 \cdot \text{FeSiO}_3$. It is highly fibrous, like chrysotile, but its fibers have a higher tensile strength and a much lower resistance to heat. Its color is a characteristic lavender-blue, and it is thus often called "blue asbestos" or "cape blue" (from Cape Province, South Africa). Fibers commonly range in length from less than $\frac{1}{8}$ to $1\frac{1}{2}$ in. and rarely exceed 3 in. It has a specific gravity of 3.20 to 3.30 and a silky luster.

Anthophyllite is an anhydrous iron-magnesium silicate, having the formula $(\text{Fe}, \text{Mg})\text{SiO}_3$. It belongs to the orthorhombic group of the amphiboles. It occurs in rather coarse, fairly long, and usually rather brittle fibers of low tensile strength. It is more resistant to heat and to acids than chrysotile, so that anthophyllite low in iron is especially suitable for making chemical fibers.

Amosite is an iron-rich anthophyllite found chiefly in South Africa. It was thought originally to be a new species and was described by Hall¹⁴ as a monoclinic amphibole. Wherry³⁰ later examined amosite both chemically and microscopically and found it practically identical with ferroanthophyllite, an orthorhombic amphibole having the formula $(\text{Fe}, \text{Ca}, \text{H}_2, \text{Mn})\text{O} \cdot \text{SiO}_2$. When amosite contains considerable soda it approaches crocidolite in composition. Amosite is characterized by a well-developed fibrous structure, having fibers of unusual length. Lengths of 4 to 7 in. are common and an extreme length of a little over 11 in. has been observed. The fibers are flexible, but usually have less tensile strength than chrysotile. Amosite is harder and harsher than chrysotile and is said to cause excessive wear on the teeth of carding machines. It varies in color from a pale dirty-brown through various shades of gray and pale yellowish green to nearly white. Acids have little effect on amosite and it withstands heat better than crocidolite.

Asbestos, "*amphibole*" *asbestos*, "*hornblende*" *asbestos*, and "*Italian*" *asbestos* are various terms given to the monoclinic amphiboles, tremolite, $\text{CaMg}_3(\text{SiO}_3)_4$, and actinolite, $\text{Ca}(\text{Mg}, \text{Fe})_3(\text{SiO}_3)_4$, when they occur in fine silky fibers. This is the original type of material to which the mineralogical name "asbestos" was given. The fibers may be fine, silky, and of great length, but they usually have little tensile strength. A small amount of Italian amphibole asbestos has been used for spinning, but most of it is too weak. When pure, tremolite asbestos is chemically stable and may be used for making chemical fibers.

Mountain leather and *mountain cork* are, respectively, thin and thick flexible sheets made up of interlocked fibers. The "cork" variety has the elasticity and lightness of cork. It is usually from light-brown to white in color and has a specific gravity of 0.68 to 0.99. One analysis⁹ of mountain cork showed silica,

57.20 per cent; peroxide of iron, 4.37 per cent; magnesia, 22.85 per cent; lime, 13.39 per cent; and water, 2.43 per cent; total, 100.24 per cent.

Mountain wood is a compact, fibrous substance made up of interlaced mineral fibers and closely resembling dry wood. It is usually gray to brown in color. It is sometimes found in Canadian asbestos deposits.

These three materials are described in Dana's *Mineralogy** as amphiboles, under actinolite, containing little or no alumina.

*Paligorskite*¹² is closely akin to mountain leather, but is relatively high in alumina and is classified by Dana as an aluminous variety of amphibole, probably an altered asbestos. While several mineralogical occurrences have been noted only one deposit has been suggested as of possible commercial interest. This is on Lemesurier Island, near the entrance of Glacier Bay, in the northern part of southeastern Alaska. Here small lenses in fracture zones in limestone contain layers of paligorskite up to 10 in. or more in thickness. It has little wet strength and probably could be pulped and reformed on a paper machine to make a paper of cardboard. No data on possible reserves are available.

While none of these materials has been used commercially it is possible that, if deposits of sufficient size were found, they could be made to yield commercially valuable products.

Analyses of Asbestos. Table 1 shows the average composition of the principal types of asbestos.

TABLE 1

	1 Chryso- tile	2 Crocidolite	3 Amosite	4 Antho- phyllite	5 Amphi- bole
SiO ₂	40.49	51.22	49.58	57.12	57.72
Al ₂ O ₃	1.27	.....	2.25	0.75	0.53
Fe ₂ O ₃ and FeO.....	2.53	34.08	39.64	6.36	2.80
MgO.....	41.41	2.48	4.79	29.44	22.61
CaO.....	.....	0.03	0.53	.....	13.84
Na ₂ O.....	.....	7.07	.....	.....	0.50
H ₂ O (const.).....	14.06	4.50	3.16	5.47	0.81
MnO ₂.....	.....	0.10	.....	.....	.....
K ₂ O.....	.....	.....	.....	.....	0.30
Total.....	99.76	99.48	99.95	99.14	99.11

1. Canadian chrysotile; average of 11 analyses by F. Cirkel: Chrysotile Asbestos, Its Occurrences, Exploitation, Milling, and Uses, *Can. Bur. Mines, Bull.* 69, 1910, p. 31.

2. South African crocidolite; analysis quoted by Cirkel, *op. cit.*, p. 22.

3. Amosite, Transvaal, South Africa; average of seven rather widely varying analyses quoted by E. T. Wherry, Amosite, *Am. Mineral.*, Vol. 6, No. 12, p. 174, December, 1921.

4. Anthophyllite, Georgia; analysis quoted in "Asbestos (1913-1919)," p. 6, Imperial Mineral Resources Bureau (Great Britain), 1921.

5. Italian amphibole asbestos; analysis quoted by B. Marcuse, The Marketing of Asbestos, *Eng. Mining J. Press*, Vol. 114, No. 7, p. 278, Apr. 12, 1922.

* DANA, JAMES, and SALISBURY, EDWARD: "The System of Mineralogy," 7th ed., John Wiley & Sons, Inc., New York, 1944.

Types of Structure*

Most asbestos minerals are found in veins, but some make up the whole mass of a rock. The veins contain both cross-fiber and slip-fiber asbestos. Cross-fiber asbestos lies perpendicular or nearly perpendicular to the walls of the vein. Chrysotile, crocidolite, and amosite occur in this way. Slip-fiber asbestos lies parallel to the walls of the vein. Chrysotile, tremolite, actinolite, and anthophyllite occur in this way. Much slip-fiber chrysotile is rather harsh. An excessively harsh slip-fiber chrysotile is known as *picrolite*. Anthophyllite, tremolite, and actinolite may occur as mass fiber, the minerals forming interlocking bundles or radial groups of fibers.

Geologic Occurrence

Chrysotile. Chrysotile asbestos is found in two entirely distinct geologic associations—in altered peridotite, an igneous rock very low in silica and high in magnesia and iron, and in limestone near its contact with sills or intrusive sheets of basic igneous rock.

Chrysotile occurs in peridotite in veins that either form a network in several directions through the rock or less commonly lie parallel. The peridotite near the veins is altered to serpentine. Few of the veins are more than an inch wide. The great deposits of this kind are those of Quebec and of the Ural Mountains, regions that before the First World War furnished nearly all the world's supply of asbestos. Deposits are worked in California, Wyoming, and Vermont.

Deposits of chrysotile in limestone are rather widely distributed, but compared to those in peridotite they are small. The fiber may be rather harsh, but it is very long, unbroken fiber over 6 in. in length and of the finest quality having been found, whereas fiber over 2 in. in length is very rare in the deposits formed in peridotite. Chrysotile occurs with serpentine at or near its contact with sills of olivine diabase, usually the upper contact. The deposits in Arizona and in the Carolina district of the Transvaal are of this type. Deposits in limestone are found in Arizona, in southwestern Montana, and probably also in New Mexico.

Anthophyllite. Deposits of mass-fiber anthophyllite occur in Georgia, North Carolina, and Idaho. The occurrence of anthophyllite has been most fully described by Hopkins.¹⁵ The anthophyllite in Georgia is a product of the alteration of peridotite. The altered rock consists almost entirely of anthophyllite. Hopkins points out that the fiber in the commercially valuable deposits has been greatly softened by weathering, which in this region has been very active. In fact, the anthophyllite appears to have been made fibrous by weathering, for the fresh anthophyllite, although it has a good prismatic cleavage, is splintery and of little or no value.

Two interesting deposits of slip-fiber anthophyllite in Maryland and California have recently been operated.

Crocidolite. The only worked deposits of crocidolite and amosite are in the Union of South Africa. Both occur as cross-fiber veins parallel to the bedding of an iron-rich siliceous argillite locally known as "ironstone." According to the published descriptions, the material of which the vein minerals are composed has been derived from the enclosing rocks as a result of regional metamorphism. The deposits cover a wide area over which they occur at the same stratigraphic horizon.

Actinolite and Tremolite. Actinolite and tremolite usually occur in veins as slip

* This section and the following section on Geologic Occurrence are taken from Edward Sampson, Asbestos in 1920, *Mineral Resources of the United States*, Pt. 2, pp. 312-313, U.S. Geol. Survey, 1920.

fiber, generally in highly magnesian rocks. They appear to have been formed by metamorphic agencies, which have also extensively affected the country rock.

Geographical Distribution. While deposits of asbestiform minerals are widely distributed over the world, there are but few localities in which high-grade spinning fibers have been found in large enough deposits to have become important sources of commercial production. In the earlier days in the industry there was little market for fibers shorter than $\frac{1}{4}$ in., and unless a deposit contained a large percentage of these longer fibers, it was not commercially profitable to work it. More recently the demand for shorter fibers has increased greatly, and deposits relatively deficient in the longer fibers may now be worked successfully. For example, the longest fiber grade now produced at Eden, Vt., is shingle stock grading 0-2-10-4, which contains only about 17 per cent coarser than 4 mesh.

The world's largest producers of spinning fiber asbestos are, in order of importance, Canada (Quebec), southern Africa (Southern Rhodesia, Union of South Africa, and Swaziland), and Russia, with Canada producing 8 to 10 times as much as its nearest competitor, Southern Rhodesia. The United States is a very small producer, domestic production of all types of asbestos taking care of less than 4 per cent of apparent consumption. Bowles⁴ gives an excellent account of world deposits to about 1936.

Canada. Not only is Canada the largest producer of spinning fiber asbestos in the world, but also its fiber is generally regarded as of the highest grade marketed in important quantities. While asbestos occurs in a number of areas in Canada, the only deposits that have been of great commercial value are located in an area of Cambrian serpentine rocks which extends from northern Vermont to the Gaspé Peninsula. In this belt the main producing districts are Thetford Mines-Coleraine-Black Lake-East Broughton area and the Asbestos-Danville-Tingwick area. These districts are more or less due south of the city of Quebec and 50 to 85 miles away from it. Asbestos is about 40 miles southwest of Thetford Mines, but the over-all length of the two areas is 60 to 70 miles and a maximum of 5 to 6 miles wide. The deposits are in the Notre Dame Hills, the Canadian extension of the Green Mountains in Vermont.

The chrysotile veins intersect portions of the serpentine in every direction, but they usually follow straight lines. The cross-fiber veins vary in thickness from mere threads up to 2 or 3 in., but the bulk of the asbestos mined is from $\frac{1}{4}$ to $\frac{1}{2}$ in. in length. The longer fiber is often divided in the middle by a seam of serpentine carrying magnetite or chromite. Usually, the asbestos can be easily separated from the rock. Slip fiber occurs along slickensided fault planes, and the fiber is arranged parallel to the walls in thin films or in layers up to $\frac{3}{8}$ in. or more in thickness. The slip-fiber veins yield only mill fiber; it is often of as good grade as mill fiber prepared from cross-fiber veins, but it is sometimes rather harsh.

The Canadian deposits are very extensive, and the known ore reserves are large. Apparently, the quality or the percentage of fiber varies little with depth. While the long fiber is the most valuable, it occurs in relatively small amounts, and the chief production (by tonnage) is of the mill-fiber grades.

An extensive serpentine belt 12 miles east of Matheson, Ontario, contains

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asbestos. In 1950 a mill with an initial capacity of 50 tons per hour was placed in operation. Large tonnage production is believed possible.

The statistics in Table 2 from the Quebec Department of Mines show the distribution of Canadian asbestos sales by grades.

TABLE 2. SALES OF ASBESTOS IN CANADA, 1945 TO 1946, BY GRADES

	1945			1946*		
	Short tons	Value		Short tons	Value	
		Total	Average per ton		Total	Average per ton
Grade:						
Crudes.....	981	\$ 415,203	\$423.24	741	\$ 334,646	\$451.61
Fibers.....	219,767	16,628,467	75.66	228,234	17,174,712	75.25
Shorts.....	246,148	5,761,487	23.41	318,710	7,591,676	23.82
	466,896	\$22,805,157	\$ 48.84	547,685	\$25,101,034	\$ 45.83
Rock mined.....	8,765,370			9,127,859		
Rock milled.....	6,459,813			7,027,483		

* Preliminary.

Africa. Next to Canada and Russia in the production of high-grade spinning fiber asbestos is British Africa. The producing countries in order of importance are Southern Rhodesia, Union of South Africa, and Swaziland.

Southern Rhodesia. The Rhodesian deposits are of high-grade chrysotile, similar in quality and occurrence to the Canadian deposits. They occur in three districts. In the (1) Bulawayo district the largest mine, the Shabani, occurs in a serpentine mass 10¼ miles long by 2½ to 3 miles wide. Spinning fibers up to 3 in. long constitute 25 to 30 per cent of the fiber produced (contrasted with 6 to 8 per cent in Canada). Reserves are large. About 46 miles east of Shabani is the (2) Mashaba district, 26 miles west of Victoria. The fiber is similar to that at Shabani. In the (3) Lomagundi district, 200 miles north of Victoria, the fiber is of poorer quality and production has been much smaller. Southern Rhodesian production, 1942 to 1946, was about 55,000 to 58,000 short tons per year, second in value only to the gold production of this country.

Union of South Africa produces four kinds of asbestos, crocidolite (cape blue), chrysotile, amosite, and tremolite. The largest production comes from Transvaal, with Cape Province second, and Natal a small, occasional producer. In the 1942 to 1946 period Transvaal produced 20,000 to 28,000 tons per year, and Cape Province 7,000 to 8,000 tons per year. In the *Transvaal* chrysotile is produced¹ in the Barberton district, eastern Transvaal, between Kaapsche Hoop and Godwin River. The largest deposits here, the New Amianthus and the Munnik-Myburgh, were of high quality but small and have been nearly exhausted.² The Carolina district also produces chrysotile, 20 to 25 miles east of Carolina and at Kalkloof, 3 miles south of the Komati River, 47 miles from Carolina. Amosite occurs 30 miles north of Lydenburg in northeastern Trans-

vaal, near Penge. The amosite occurs in cross-fiber veins, in lengths up to 11 or 12 in. and averaging about 6 in. for the commercial product. Crocidolite occurs associated with amosite in the Pietersburg district in the western part of the amosite belt. In *Cape Province* blue crocidolite, known as "cape blue," occurs in cross-fiber veins in an extensive belt in northern Cape of Good Hope. This belt of sedimentary, bedded ironstones is about 240 miles long with a maximum width of 30 miles, extending from 30 miles south of Prieska northerly beyond Kurman. Many deposits have been found throughout the belt, and reserves are reported to be very large. The fiber ranges from less than $\frac{1}{2}$ in. to 1 or 2 in. in length. *Natal* is a small, intermittent producer of both chrysotile and brittle tremolite asbestos.

The most important statistics of the production of asbestos in the Union of South Africa are shown in Tables 3 and 4 by the U.S. Bureau of Mines.

TABLE 3. ASBESTOS PRODUCED IN AND EXPORTED FROM THE UNION OF SOUTH AFRICA, 1944 TO 1948^a

Year	Production, short tons				Exports ^b	
	Transvaal	Cape Province	Natal	Total	Short tons	Value
1944	26,747	7,835	c	34,582	28,174	\$ 672,941
1945	20,016	8,200	c	28,216	22,005	591,124
1946	12,636	7,589	c	20,225	21,481	557,008
1947	21,959	8,183	c	30,142	33,237	927,371
1948	37,434	8,301	c	45,735	38,550	1,138,792

^a Data from Union of South Africa, Department of Mines, Quarterly Report.

^b Revised. (Data previously listed included manufactures.)

^c Data not available.

TABLE 4. ASBESTOS PRODUCED IN THE UNION OF SOUTH AFRICA, 1944 TO 1948, BY VARIETIES AND SOURCES, SHORT TONS*

Variety and source	1944	1945	1946	1947	1948
Amosite (Transvaal).....	22,848	16,737	9,838	18,780	30,372
Chrysotile (Transvaal).....	2,014	1,765	1,666	2,253	4,441
Blue (Transvaal).....	1,831	1,471	1,102	896	2,608
Blue (Cape).....	7,835	8,200	7,589	8,183	8,301
Anthophyllite (Transvaal).....	54	43	30	30	13
	34,582	28,216	20,225	30,142	45,735

* Data from Union of South Africa, Department of Mines, Quarterly Report.

Swaziland. This country is a relatively new producer, but the Havelock mine near the Transvaal border is one of the largest in the world. The deposits contain high-grade chrysotile and are probably an extension of the Barberton district of the Transvaal. The product is shipped by a 12½-mile aerial tramway to Barberton Station. The record production was nearly 30,000 tons in 1944.

Russia is probably the second largest producer of high-grade spinning fiber asbestos, but production statistics have not been available since 1938, when she was reported to have produced 86,000 metric tons (125,000 tons in 1937). Russia is unique in that she is the only large asbestos-producing country who is also a large consumer. Before the Second World War exports were important in world trade, but in recent years our imports from Russia have been relatively small and it is presumed that she has been consuming most of her production. The fiber is high-grade chrysotile similar to that from Canada. The most important deposits are in the Bajenova district of the Urals, 90 miles northeast of Sverdlovsk (Ekaterinburg). It was reported before the war that her reserves were estimated at 18 million tons of fiber. The principal production center is at Asbest, where 20 or more open pits have been worked. Other smaller production districts are at Minusinsk on the Yenisei River near the Mongolian border in eastern Siberia; in the Altai Mountains southwest of Minusinsk; and on the Laba River in the Maikop district of the Caucasus.

The United States produces both spinning fiber chrysotile and nonspinning fiber amphibole, but in very small quantities compared to domestic consumption. Chrysotile is produced in quantity only in Vermont and Arizona, although very small occasional production has come from several other states (Wyoming and California, for example). The amphibole types, tremolite and anthophyllite, have been produced for filter fibers, cements, etc., in small quantities. Present producers (1946) are in California, Georgia, and North Carolina.

Vermont is the largest producer of high-grade chrysotile. The deposits, extensions of those in Quebec, occur near Lowell, Eden, and Hyde Park in Lamoille and Orleans Counties in the extreme northern part of the state. Both cross and slip fiber occur, the former generally under $\frac{1}{2}$ in. in length. Slip fiber up to 3 or 4 in. long is found, but it is coarser than the cross fiber and not suitable for spinning. Practically no long-fiber crude is produced, and all rock goes to the mills to produce mill fiber grading 0-2-10-4 (shingle stock) or lower. One large mill is operated near Eden.

*Arizona*²⁹ asbestos deposits are the only ones so far discovered in the Western Hemisphere yielding iron-free chrysotile spinning fiber that meets the Navy specifications for covering electric cables. Unfortunately they are small, remote, and very difficult of access. They occur scattered over 25 townships in Gila County, 35 to 100 miles from Globe, the nearest shipping point, in the Salt River and Cherry Creek Basins; on parts of the Fort Apache and San Carlos Indian Reservations; and portions of the Tonto and Crook National Forests. The veins, of the cross-fiber type, occur associated with serpentine in limestone. The best quality fiber, up to 6 in. long, is soft, fine, silky, of high tensile strength, very low in iron, and of excellent spinning quality. In places a harsher fiber is associated with the soft. The greatest concentration of producing properties has been in the Chrysotile district, a 100-square-mile area on both sides of the Salt River, roughly 30 miles northeast of Globe. In this district are the Johns Manville, Regal, Phillips, Pine Top, Enders, Fiber King, and other mines. Several mills are operated.

Wyoming. Deposits of cross- and slip-fiber chrysotile asbestos occur in Wyoming in several localities and fiber has been produced in small quantities at various times in the past. These deposits are located (1) on Caspar Mountain, 8 miles south of Caspar; (2) on Smith Creek, 20 miles southeast of Caspar; (3) 28 miles south of Lander; (4) near Berry Creek in Lincoln County, on the north side of Forellen Peak, 35 miles from the nearest shipping point at Ashton, Idaho.

Some of the Wyoming fiber is 1 in. long, but most of it is much shorter and but a very small proportion is of spinning grade. There has been no production in recent years.

California. While asbestos, of both the chrysotile and amphibole varieties, has been found in at least 12 counties in California, and a small production obtained from a few properties, no large deposits of high-grade spinning fiber have been developed. Most of the deposits are apparently small or of low grade, and production has been only a few tons a year.

In 1946 there was some production of tremolite filter fiber near Castella and Hazel Creek, Shasta County, and from the Loma Blanca mine in the same county. There has been some activity at the Morgan mine (chrysotile), Placer County, near Monticello, Napa County, and at Chicago Park, Nevada County, in recent years, but no production.

Other States. *Georgia* has many occurrences of amphibole asbestos suitable for cements, paints, and, in part, for chemical filters in a belt across the northwestern part of the state from Rabun to Harris Counties. Deposits worked for many years 3 miles southwest of Sall Mountain, White County, and near Hollywood, Habensham County, have been inactive for some time. Chemical fiber production now comes from Dillard, Rabun County, and from just across the state line in Macon County, *North Carolina*. The latter state also has deposits of anthophyllite near Minneapolis, Avery County. A deposit at Pickens, Pickens County, *South Carolina*, produced a small amount of anthophyllite in 1939.

Maryland for many years produced tremolite filter fiber near Pylesville, Harford County, but these deposits are said to be exhausted. Short-fiber anthophyllite has been produced in recent years in Montana, near Gallatin Gateway, Gallatin County, and near Libby, Lincoln County. *Oregon* has produced a small amount of amphibole filter fiber near Rogue River, Jackson County, near Mount Vernon, Grant County, and near Hereford, Baker County, and chrysotile has been reported from Malheur County. Amphibole asbestos was produced at Burlington, *Washington*, in 1934.

Alaska produced a small quantity of high-grade long-fiber amphibole for filter fiber during the Second World War at Shungnak in the Dahl Creek area of the Kobuk River district in the northwestern part of the territory. Long slip-fiber chrysotile of high quality also occurs in thin veins in this general area. Deposits of amphibole asbestos also occur at the Bear Creek Mine on Admiralty Island and at Chitina on Copper River. There was a small production of amphibole filter fiber in Chester County, *Pennsylvania*, in 1940. A deposit of brittle-fiber anthophyllite was operated for some years in *Idaho*, 14 miles southeast of Kamiah,

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Idaho County. A mill was built, and the product was used in pipe and boiler coverings, paints, cements, etc.

Other Countries. Cyprus. Large deposits of asbestos occur on the island of Cyprus, and production has been important. Both chrysotile and anthophyllite are found, the former at Amianods, on Mount Troodos in the Limasol district. The best grades come from Paphos. Much of the material produced is short fibered, but some is of a grade that may be mixed with Canadian fiber.

Italy is a small producer of asbestos, most of which is apparently of the amphibole variety. There are three asbestos districts in Italy: (1) in the Susa Valley near Mount Cenis; (2) in the Aosta Valley, from Ivrea to Chatillon; and (3) in the Valtellina district of Lombardy, near Sondrio. Italy does not produce sufficient fiber for her own needs, but imports chiefly from Canada and Africa.

TABLE 5. ASBESTOS SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948, BY VARIETIES

Year	Chrysotile		Amphibole		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944	6,275	\$373,122	392	\$7,222	6,667	\$ 380,334
1945	11,986	442,056*	240	3,989	12,226	466,045*
1946	13,645	499,260	430	5,504	14,075	504,764
1947	23,586	912,340	449	6,218	24,035	918,558
1948	^a	^a	^a	^a	37,092	1,806,261

* Revised figure.

^a Bureau of Mines not at liberty to publish figure separately.

Bolivia has deposits of blue crocidolite, somewhat inferior to cape blue, in the Chapare region, Cochabamba Department. Fibers have a maximum length of 5 in. Small shipments were made to Japan before the Second World War.

Venezuela has chrysotile deposits near Tinaquilla, State of Cojedes, and a mill was completed there in 1946.

Australia. In South Australia, 10 miles north of Hawker and 248 miles north of Adelaide, is a deposit of good-grade blue crocidolite from which some production has come. In Western Australia there are operating deposits of high-grade blue crocidolite in the Hammersley Ranges.¹¹ Transportation is poor, but hand-cobbed crudes, with fiber length of up to 1¾ in., is produced, and a little has been marketed in this country.

New occurrences reported in the past few years include a large deposit of amosite near Wadi Hafafit in the Baramia district of *Upper Egypt*; near Bou Asser, *French Morocco*, there is reported a deposit of cross-spinning fiber asbestos up to 2 in. long, used in Casablanca; in the Lewis Brook area on the west coast of *Newfoundland* are deposits of chrysotile believed to be of commercial importance.

Asbestos deposits, of both the chrysotile and amphibole types, are known in many other countries, and from some of them have come small and irregular productions, but none of them are of great present importance. This may be

due to small size of deposits, low grade of fiber, or remoteness from transportation and markets.

Some of the countries in which deposits of asbestos have been worked or have been reported are *China, Japan, India, Finland, Switzerland, Greece, Turkey, Portugal, Spain, France, Germany, Norway, and Great Britain.*

Production and Consumption. Tables 5 to 8 from the U.S. Bureau of Mines give the most important statistics of the asbestos industry.

TABLE 6. WORLD PRODUCTION OF ASBESTOS, 1941 TO 1948, BY COUNTRIES, METRIC TONS¹

Country ^a	1941	1942	1943	1944	1945	1946	1947	1948
Argentina.....	84	51	349	b	b	b	b	b
Australia:								
New South Wales.....	38	142	422	353	500	241	200	b
South Australia.....	152	64	11	6	7	8	40	40 ^b
Tasmania.....	4	7	19	105	281	b	b	b
Western Australia.....	62	121	247	313	1,036	380	1,089	977
Bolivia.....	211 ^c	58 ^c	22 ^c	13 ^c	61 ^c	b	76	147
Brazil.....	13 ^c	b	b	b	b	b	3	10
Canada (sales) ^d	433,492	398,699	423,831	380,349	423,559	506,371	600,391	650,230
China.....	20,515	20,615	b	b	b	b	b	b
Cyprus (exports).....	4,874	3,128	1,186	1,983	3,125	5,993	6,369	8,108
Egypt.....			7	240	50 ^e	65	1,015	1,625
Finland ^f	3,842	4,679	7,466	7,733	4,197	5,781	b	b
France.....	b	b	b	b	1,016	575	475	b
French Morocco.....		116	182	507	b	446	700	399
Greece.....	b	b	b	b	b	b	b	b
India.....	372	514	293	592	b	312	123	b
Indochina.....	22	146	312	2,450		b	b	b
Italy.....	10,766	11,695	7,419 ^g	b	4,811	8,811	10,468	11,770
Japan.....	b	1,526 ^h	6,418	9,395 ⁱ	2,659 ⁱ	3,997	3,708	4,590
Kenya Colony.....	213	307	321	341	389	165 ^k	582	b
Korea (Chosen).....	b	b	b	4,815	b	b	b	b
Madagascar.....	3	11	b	3	1	1	0	0
New Zealand.....	54	43	190	17	2	b	b	b
Southern Rhodesia.....	40,037	50,623	52,749	52,882	51,118	50,686	49,073	62,502
Spain.....	2	84	50		b	b	b	b
Swaziland.....	19,166	23,219	17,179	29,628	21,243	29,155	25,360	29,421
Switzerland.....		6	11	7	35	49	b	b
Turkey.....	146	295	133	231	138	55	b	203
Uganda.....	b	b	b	b	b	b	b	b
Union of South Africa.....	25,422	31,351	32,346	31,372	25,597	18,348	27,344	41,499
U.S.S.R.....	b	b	b	b	b	b	b	b
United States (sold or used pro- ducers).....	22,127	14,044	5,456	6,048	11,691	12,769	21,894	33,649
Venezuela.....	b	b	b	b	b	65	293	192

^a In addition to countries listed asbestos is produced in Algeria, Bulgaria, and Czechoslovakia.

^b Data not available.

^c Exports.

^d Exclusive of sand, gravel, and stone (waste rock only), production of which is reported as follows: 1938, 2,975 tons; 1939, 3,535 tons; 1940, 5,890 tons; 1941, 7,669 tons; 1942, 7,329 tons; 1943, 6,272 tons; 1944 to 1946 data not available.

^e January to September, inclusive.

^f Includes asbestos flour.

^g January to June, inclusive.

^h Approximate.

ⁱ Incomplete figure.

Crude asbestos is imported in the United States from a number of countries; Canada, Southern Rhodesia, Union of South Africa, and Russia have been the chief sources of supply. In 1948 Canada supplied 93 per cent of the tonnage and 84 per cent of the dollar value of all imports.

In recent years asbestos consumption has grown at a faster rate than production. Some asbestos-products plants have been built without due regard for the supply of raw asbestos. This has led to acute shortages and, in some instances, to the temporary closing of asbestos products plants. There has been increased interest in the reclaiming of asbestos from scrap. The increased demand for very short fibers for floor and wall tile and other uses has led to the reworking of mill dumps and to the more efficient recovery of very short fiber in current milling operations.

Messel states that "the present known reserves of proven commercial value (excluding Russia) are being depleted at an alarming rate, about 10 million tons of ore being mined annually. No new deposits have come into production during the last 15 years, with the exception of certain deposits in Africa, which are the most promising, and minor developments in Canada, Venezuela, Cyprus, Australia, and Brazil."¹⁹ The African deposits hold the best promise for large reserves, but unless new deposits are developed shortages may be acute in 20 years.

Mining and Milling. In Canada the methods of mining are (1) open quarries, (2) open pits with glory holes, (3) shrinkage stoping, (4) block caving. By far the largest tonnage removed has been by the first two methods. The tendency is toward more underground mining. In 1946 seven companies mined over 9 million tons of asbestos rock and waste from 12 mines, of which 10 were open quarries with or without glory holes and 2 were underground mines using block caving. In quarrying the present tendency is to work high benches (up to 150 ft high) and blast down 100,000 tons or more of rock at a shot. An interesting feature of asbestos mining is that no wood may be used for any purpose unless it is protected, because it is impossible to separate wood fiber from asbestos in milling.

Since the fiber recovery averages only 5 to 6 per cent of the rock mined, very large tonnages must be handled—a capacity of 1,000 tons per day is about the minimum for profitable operation. The Johns-Manville operation handles about 20,000 tons of ore and waste per day.

Milling methods used at the various mills vary in detail, but they are nearly all identical in principle. The objects of milling are to recover as much of the original fiber as possible, free from dirt and adhering rock; to expand and fluff up the fiber; to handle the ore as gently as possible in order to minimize the reduction in fiber length by attrition; and to grade the fibers into different length groups best suited to use requirements. The general method in use is (1) coarse crushing in jaw or gyratory crushers, sometimes in two stages, to 1½ to 2 in.; (2) drying to 1 per cent or less moisture, in rotary or vertical inclined-plane driers; (3) secondary crushing in short head cone crushers, gyratories, or hammer mills; (4) screening, usually in flat shaking or gyratory screens; (5) fine-crushing and fiberizing in stages, each stage followed by screening, during which air suction

above the screens effects separation of the fiber from the rock; (6) collection of the fiber in cyclone separators, which also remove the dust; (7) grading of fibers in punched-plate trommel screens; (8) blending of products to make specification grades; (9) bagging for shipment.

If the ore has recoverable crudes, that is, long spinning fiber, a picking belt may follow the first coarse crusher. Fiberizing or opening up the bundles of fiber (step 5) is done in a special type of beater or impact mill designed to free the fiber from the rock and fluff up the fiber without reduction in fiber length. Three types of mill are used in Canada, all essentially hammer mills. The Jumbo mill is a horizontal cylinder with corrugated liner and a shaft with beater arms run at 600 rpm. It has a tendency to cut up the fiber, and the trend is to replace it with a combination of crushers and vertical-type mills, the Torrey Cyclone or the impact mill. Both mills are vertical cylinders with corrugated liners and vertical shafts with beater arms, running at 900 to 1,000 rpm. The Torrey Cyclone has two sets of hammers with a hopper in between, and the impact mill has only a single set.

The screening operations are perhaps the most critical. The air in the exhaust hoods over each screen must be so adjusted that only the properly fiberized material will be lifted, leaving the rock and unopened fiber bundles for further fiberizing. The air system uses 20 to 25 per cent of the total power consumed in a mill.

The dust removed in the cyclone fiber collectors carries a certain amount of fine asbestos fiber, called "floats," which may be recovered. At one mill tailings are recovered from old dumps, screened through $\frac{3}{8}$ in., and passed through wet cone classifiers. The fiber is floated off, filtered, dried, fluffed up, and packed for shipment.

A generalized but rather detailed flow sheet of a modern mill is given by Rice²³ (see also Messel¹⁹).

In South Africa in past years there has been little or no market for very short mill fibers, and they were wasted or stored for possible future treatment. Hence, earlier production statistics were not comparable with those of Canada, where there were markets for the short fibers. However, with present market conditions and with the development of industrial markets in South Africa the situation is somewhat different today.

Specifications, Grades, and Tests. Since for most important commercial uses strong, flexible fiber is needed, the brittle anthophyllite type of asbestos needs little mention here. The chief exception is that of filter-fiber asbestos. For this purpose a fairly strong fiber is needed, and the asbestos must be of such chemical composition that it is practically unaffected by common acids and alkalis. Tremolite is often used for this purpose.

Some of the physical properties that good asbestos fibers must possess for various uses are as follows: good fiber length; good flexibility; fine fibers; silkiness; high tensile strength; resistance to acids and alkalis; resistance to sea water and moist air; high melting point; resistance to heat; high heat-insulating value; high electrical-insulating value; and good "spinnability," that is, capability of being easily spun into products of good quality without undue loss and breakage

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of fiber. There are now so many and such diversified uses for asbestos that not all these properties are necessary for any single use. Thus, short fibers may be used for asbestos-paper and asbestos-cement shingles, while long fibers are needed for asbestos textiles. For some purposes two or more types of asbestos with different physical properties (for example, crocidolite and chrysotile) may be mixed advantageously.

A comparison of some of the physical properties of crocidolite, chrysotile, and amosite is given in Table 7.

TABLE 7. COMPARISON OF PROPERTIES OF CHRYSOTILE, CROCIDOLITE, AND AMOSITE*

Property	Chrysotile	Crocidolite	Amosite
Fiber length (usual maximum).....	1½-2 in.	1½-3 in.	7 in.
Tensile strength.....	High	Higher than chrysotile	Good
Flexibility.....	High	High	Good
Fineness of fiber.....	Very fine	Fine	Fine
Resistance to heat.....	Good, but becomes brittle	Poor; fuses to a glass	Good, but becomes brittle
Resistance to acids, alkalies, and sea water.....	Poor	Good	Good
Electrical-insulating value.....	Fair to good	Good	
Heat-insulating value.....	Good	Good for moderate heat	Good
Spinnability.....	Excellent	Fair	Fair

* The properties noted above apply to best grades of each type. Authorities, F. Cirkel, *Chrysotile Asbestos, Its Occurrence, Exploitation, Milling, and Uses*, *Can. Bur. Mines, Bull.* 69, 1910; and A. L. Hall, *Asbestos in the Union of South Africa*, *Geol. Survey S. Africa, Mem.* 12, 2d ed., 1930.

For spinning purposes, Canadian chrysotile is considered the best in the world. Arizona chrysotile is good, but is apt to be lacking in uniformity and to contain harsh, brittle fibers. Some users state that the fiber is so fine and silky that there are large losses in spinning. Crocidolite is not in high favor in the United States, because it is rather difficult to fiberize properly; it is rather dirty and dusty compared with Canadian chrysotile; and its fusion point is low. Crocidolite and amosite, usually mixed with some chrysotile, however, are used much more extensively in England and Europe. Amosite fiber is harsher than chrysotile, and is rather dirty and dusty to handle.

Asbestos is often erroneously called a refractory material, but it cannot properly be so classed. Crocidolite fuses at a relatively low temperature to a black glass. Both chrysotile and amosite lose their water of composition at a moderate temperature and become inflexible and very brittle. Nor has asbestos alone a high heat-insulating value, compared with such materials as basic magnesium carbonate. Asbestos is noncombustible and capable of being woven into fabrics, and these are the properties upon which much of the value of high-grade asbestos depends.

The quality of asbestos and its suitability for most uses may be easily determined by a few simple tests. Length, color, silkiness, flexibility and, to some extent, fineness of fiber and tensile strength may be determined by inspection. A sample of asbestos should be fiberized by rubbing or crushing it between the

fingers. Single fibers may then be tested for flexibility and tensile strength by bending and breaking. Several fibers may be twisted into a strand or yarn and again tested for flexibility and strength. Asbestos of good quality should be easily fiberized, soft, silky, strong, flexible, and easily twisted into a strong yarn. Fibers $\frac{1}{4}$ in. or more in length and otherwise of good grade are of commercial interest.

The grading of asbestos for market varies in different districts and at different plants. In Canada there are two main grades, crude and fiber, each of which is divided into subgrades, in each case based on length of fiber. Crude, produced entirely by hand picking and cobbing, consists of all cross-fiber asbestos over $\frac{3}{8}$ in. long. No. 1 crude consists of fiber over $\frac{3}{4}$ in. long (average 1 in.). No. 2 crude consists of fiber from $\frac{3}{8}$ to $\frac{3}{4}$ in. long (average $\frac{5}{8}$ in.).

Mill fibers in Canada are classified by a standard screen test made on a Quebec standard testing machine. This consists of four wooden trays, $24\frac{1}{2}$ by $14\frac{3}{4}$ by $3\frac{1}{2}$ in. deep. The top, or No. 1, tray has a wire screen bottom with a $\frac{1}{2}$ -in. opening (0.105-in. wire); No. 2, a 4-mesh screen (0.063-in. wire); No. 3, a 10-mesh (0.047-in. wire); No. 4 is a solid-bottom pan. The nest of screens is fastened to a frame, so arranged that it may be vibrated horizontally with a $1\frac{1}{2}$ -in. throw by an eccentric revolving at 300 rpm. In making a test, 1 lb (16 oz) of fiber is placed in the top tray and shaken for exactly 2 min. The residue on each screen and in the bottom pan is weighed separately and the weight recorded in ounces. Thus, a fiber testing 0-8-6-2 (total 16 oz) is one of which 8 oz is retained on the second screen, 6 oz on the third, and 2 oz of shorts in the pan.

Fibers are divided into nine main groups that are again subdivided into about 25 standard grades, each having a different test and value. The main grades are:¹⁸

Crude Fibers (Hand-processed).

Group 1: Crude No. 1, $\frac{3}{4}$ in. staple and longer

Group 2: Crude No. 2, $\frac{3}{8}$ in. staple and longer, up to $\frac{3}{4}$ in.

Mill Fibers (Machine-processed).

Group 3: Textile spinning fibers (testing over 0-8-6-2)

Group 4: Shingle fibers (testing below 0-8-6-2 and including 0-1.5-9.5-5.0)

Group 5: Paper fibers (testing below 0-1.5-9.5-5.0 and including (0-0-8-8)

Group 6: Waste stucco-plaster fiber (testing below 0-0-8-8 and over 0-0-5-11)

Group 7: Shorts (testing 0-0-5-11 and below)

Group 8: Sand weighing over 35 lb per cu ft and under 75 lb

Group 9: Sand and gravel weighing over 75 lb per cu ft

Shorts are not sold on length but according to color and cleanliness. Color is of prime importance. Asbestic is finely ground asbestos sand-mill tailings.

Some mines in Africa and Russia do not use the Canadian classification but have their own standards. These vary somewhat, but are fundamentally based on fiber length.

Each type and grade of asbestos has certain types of use for which it is best fitted. For electrical insulation Rhodesian and Arizona chrysotile are demanded because they are low in iron. Amosite is used extensively in 85 per cent magnesia

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and other high-temperature molded heat insulation and for woven insulation for navy ships. Blue crocidolite is used for asbestos-cement pipe. The Army and Navy Munitions Board is stock-piling certain grades of amosite and long-fiber chrysotile from Africa.

Markets and Prices. The United States is the largest consumer of asbestos and manufacturer of asbestos products, with the United Kingdom standing second. Before the First World War the chief international marketing point was Hamburg, but in recent years New York has taken the lead. Much of the South African and Rhodesian asbestos is marketed in London. Some of the largest manufacturers of asbestos products own mines in Canada or elsewhere that partly or wholly supply their needs for raw asbestos. Smaller consumers buy either directly from the producers or from dealers and agents.

Asbestos crudes and fibers are packed in 100-lb bags and sold at a price (including cost of bags) per 2,000-lb ton, usually fob cars mines. Crudes bulk about 40 cu ft per 2,000-lb ton, and fibers 60 to 90 cu ft per ton. Sand and shorts are sold by the net ton and shipped either in bags or in bulk. Most producers have certain brand or grade marks (thus X, XX, and C grades), but, while the same marks may be used by different producers, the grades do not necessarily correspond. Most asbestos is sold on sample and test.

Since asbestos from different producing areas varies widely in type, quality, and adaptability for use, prices also vary widely. In this country prices on Canadian asbestos more or less set general market values. *Metals and Mineral Markets*, Mar. 17, 1949, lists the following prices for asbestos fibers, effective Jan. 1, 1949, fob Quebec mines, United States funds:

<i>Quality</i>	<i>Per Short Ton</i>	
Crude No. 1 (spinning fiber over $\frac{3}{4}$ in. long).....	\$960.00–	\$1,050.00
Crude No. 2 (spinning fiber $\frac{3}{8}$ – $\frac{3}{4}$ in. long).....	492.00–	550.00
Spinning fibers.....	232.00–	475.00
Shingle stock.....	95.50–	141.00
Paper stock.....	78.50–	88.00
Waste.....	58.00	
Shorts.....	27.00–	52.00
<i>Fob Hyde Park, Vt.</i>		
Shingle fiber.....	\$97.00–	\$107.00
Paper-stock fiber.....	68.50–	85.00
Waste.....	56.00	
Shorts.....	25.50–	46.50

Utilization. The uses for asbestos are so many and so varied that a simple enumeration of all of them cannot be given here. The main uses for asbestos fall into a few fairly well-defined groups, namely, (1) asbestos yarns, cordage, cloth, and similar textile products; (2) asbestos paper, compressed sheets, blocks, etc; (3) asbestos-cement products, such as asbestos shingles, lumber, corrugated siding, etc.; (4) heat-insulating cements; (5) boiler and pipe coverings (asbestos plus basic magnesium carbonate) and corrugated asbestos paper; (6) as an ingredient in paints and roofing cements (shorts, asbestic, ground anthophyllite, etc.); (7) asbestos fibers used as such for filtering, packing, etc.

From primary manufactured products, such as asbestos yarns, cordage, and paper, a multitude of secondary finished products are produced, such as automobile brake-band linings, steam packing, and pipe coverings. It should be noted that, while very long spinning fiber is essential for some purposes, the bulk of the asbestos marketed is for use in products in which much shorter mill fibers may be used.

The use of very short-fiber asbestos in floor tile has created a large market for this product, which once was hard to dispose of. Another use for shorts that may become of some importance is in nonferrous foundry core sands to give better collapsibility, elasticity, and venting qualities.

Automobile brake-band linings and gaskets are very important and essential uses for asbestos.

While statistics of asbestos consumption by uses are not available, Table 8 by the U.S. Bureau of Mines, showing exports of manufactured products, gives some idea of the importance of some of the uses.

TABLE 8. MANUFACTURED ASBESTOS PRODUCTS EXPORTED FROM THE UNITED STATES, 1945 TO 1946, BY KINDS

Products	1945		1946	
	Quantity	Value	Quantity	Value
Brake lining:				
Molded and semimolded, short tons..	1,093	\$1,580,652	1,248	\$1,837,752
Not molded, ft.....	353,028	236,099	740,670	368,680
Clutch facing, number.....	1,360,846	555,995	1,196,241	500,046
Paper, millboard, and rollboard, short tons.....	754	136,019	653	141,837
Pipe covering and cement, short tons..	1,825	213,468	1,103	145,010
Textiles, yarn, and packing, short tons.	1,665	1,994,297	2,327	2,674,573
Asbestos roofing, squares.....	119,770	676,898	129,728	806,182
Other asbestos manufactures, except roofing, short tons.....	6,047	1,208,100	8,734	1,695,386
Magnesia and manufacturers, short tons.....	9,131	662,559	17,423	1,093,626
		\$7,264,087		\$9,263,092

Bowles⁴ gives a good short account of the manufacture of asbestos products.

Substitutes for Asbestos. As yet no effective substitutes for asbestos have been found for most uses. In recent years a shortage of asbestos has increased the interest in substitutes and, for some uses, interesting products have been developed; for example, a fireproof wallboard for interiors made from cement and treated wood fibers. New uses for asbestos and expansion of markets for older uses, however, have continued to tax the available supply.

With the continued improvement in glass fibers it is possible that an efficient substitute from this material will eventually be made. The inherent defects in glass fibers so far have been brittleness, insufficient fineness of fiber, and lack of

tensile strength. While asbestos fibers can theoretically be almost infinitely subdivided, glass fibers, drawn to a definite fineness, cannot be further split without breaking. However, it has been found that blends of glass and asbestos fibers often result in products with better properties than from asbestos alone.²²

Before the Second World War it was reported from Germany that a synthetic asbestos of the same composition and physical properties as Canadian chrysotile had been developed, but no commercial production resulted. During the war Germans claimed to have made a low-quality amphibole by crystallation from a vapor. With our widely increasing knowledge and experience in the growing of synthetic crystals it seems possible that this problem will eventually be solved.

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ASPHALTS, BITUMENS, WAXES, AND RESINS

A group of organic compounds not used as fuels should be classed as industrial minerals and thus included in the scope of this work. These are the natural asphalts and bitumens, mineral waxes, and resins. The subject is far too large to be covered adequately here. The best general treatise on this whole group is that by Abraham,¹ and his work has been drawn upon freely in the preparation of this chapter. Part of the material has been taken from a brief paper by Ladoo.²

Classification of Native Bitumens. The following classification is that given by Miller³ after Abraham.¹

- I. Petroleum, liquids, viscous liquids
- II. Native asphalts, solid or semisolid
 1. Pure or nearly pure
 - a. Bermudez Lake asphalt (Venezuela)
 2. Associated with mineral matter
 - a. Trinidad Lake asphalt

TABLE 1. PROPERTIES OF NATURAL BITUMENS

	Classification	Fracture	Streak	Specific gravity at 77°F	Fusibility, °F	Fixed carbon, per cent	Solubility in carbon disulfide, per cent	Soluble in 88° naphtha, per cent	Sulfonation residue, per cent
Nonasphaltic petroleum	Petroleum			0.75-0.90	< 0	½-2	98-100	98-100	90-100
Mixed-based petroleum				0.80-0.95	< 0	2-5	98-100	95-100	85-95
Asphaltic petroleum				0.85-1.00	< 0	5-10	98-100	90-100	80-95
Ozokerite	Mineral wax			0.85-1.00	140-200	½-10	95-100	75-95	90-100
Montan wax			White to yellow	0.90-1.00	170-200	2-10	98-100	80-100	0-10
Paraffin wax			White	0.85-0.95	100-150	0-2	99-100	99-100	95-100
Native asphalts (containing less than 10% mineral matter)	Asphalt								
Native asphalts (containing more than 10% mineral matter)			Brown to black	0.95-1.12	60-325	1-25	60-98	25-95	90-100
Wurtzilite asphalt			Brown to black Brown to black	0.95-1.15 1.04-1.07	60-350 150-300	5-25 5-25	Trace-90 98-100	Trace-85 50-80	90-100 90-95
Gilsonite	Asphaltite								
Glance pitch			Brown	1.05-1.10	250-350	10-20	98-100	40-60	85-95
Grahamite			Black Black	1.10-1.15 1.15-1.20	250-350 350-600	20-30 30-55	95-100 45-100	20-50 Trace-50	85-95 80-95
Elaterite	Asphaltic pyrobitumen		Brown	0.90-1.05	Infinite	2-5	10-20	5-10	80-90
Wurtzilite			Brown	1.05-1.07	Infinite	5-25	5-10	Trace-2	90-98
Albertite			Brown to black	1.07-1.10	Infinite	25-50	2-10	Trace-2	90-98
Impsonite			Black	1.10-1.25	Infinite	50-85	1-6	Trace-2	90-98
Asphaltic shales			Variable	1.50-1.75	Infinite	2-25	Trace-3	0-trace	90-98

ASPHALTS, BITUMENS, WAXES, AND RESINS

- b. Iraq, Boeton Dutch East Indies, and Selenitza (Albania)
- c. Rock asphalts, European and American
- III. Asphaltites, hard
 - 1. Pure or nearly pure
 - a. Gilsonite
 - b. Grahamite
 - c. Glance pitch, manjak

To this classification should be added, for our purposes,

- IV. Asphaltic pyrobitumens
 - a. Elaterite
 - b. Wurtzilite
 - c. Albertite
 - d. Impsonite

The asphaltites differ from asphalt chiefly in that they usually are more difficultly fusible. Asphaltic pyrobitumens differ from the other three groups in that, while the others are almost completely soluble in carbon disulfide, they are largely insoluble.

Table 1, showing the properties of the natural bitumens, is abstracted from a more extensive table by Abraham.¹

Production and Consumption. Table 2 shows the United States production of bituminous rock, gilsonite, and wurtzilite in recent years. There is a small but as yet unreported production of ozokerite, montan wax, and coal resin. There is no domestic production of natural asphalt, but we import 4,000 to 5,000 tons of Lake asphalt from Trinidad per year (1945 to 1946) and 200 to 300 tons of grahamite from Cuba. (These statistics should be compared with domestic sales of petroleum asphalt in 1946 of about 7.6 million short tons.)

TABLE 2

Year	Bituminous rock		Gilsonite		Wurtzilite	
	Tons	Value	Tons	Value	Tons	Value
1939	422,484	2,007,810	37,289	1,053,142	75	5,842
1940	458,665	1,949,166	31,930	770,711	70	5,460
1941	654,692	2,312,227	36,407	851,623	69	5,343
1942	935,295	3,367,279	40,041	909,311	37	2,852
1943	835,648	3,096,753	50,446	1,188,485	41	3,250
1944	750,454	2,771,925	49,051	915,480	11	874
1945	642,600	2,565,925	61,273	1,250,546	0	0
1946*	777,457	2,861,591	68,407†	1,440,229	24	1,066
1947	1,004,740	3,756,074	67,165	1,746,228	a	a
1948	1,084,004	3,634,917	52,122	1,390,713	a	a

* Alabama, California, Kentucky, Missouri, Oklahoma, Texas, Utah.

† All in Utah.

a Figures not available.

ASPHALT

There is no domestic production of natural asphalt. The only important source in the Western Hemisphere today is the famous Pitch Lake deposit on the island of Trinidad, discovered in 1595 by Sir Walter Raleigh. This lake, covering

about 100 acres, lies in the crater of an extinct mud volcano and has a proved depth of 285 ft at the center. The crude asphalt, as dug, is a semihard emulsion of asphalt with about 33 per cent water and gas and 27 per cent colloidal clay and silica. It is refined by agitation with live steam to remove water and gases, but about 36.5 per cent of inorganic mineral matter and 4 per cent water of hydration remain in the refined product. In Venezuela the Bermudez Pitch Lake is located near Guanoco in the northeastern part of the country. This deposit, about 900 acres in extent and 4 to 7 ft deep, contains about 65 per cent asphalt, as dug, with 30 per cent water and gas and 5 per cent insolubles. After refining it contains 95 to 96 per cent asphalt, 2 to 2.5 per cent mineral matter, and 2 to 2.5 per cent ignition loss. Production stopped in 1932.

Bituminous Rock or Rock Asphalt. These terms denote rock naturally impregnated with asphalt. In Great Britain and generally in Europe only asphalt-impregnated limestone, by definition, is recognized under the name of rock asphalt. In the United States, however, bituminous rock covers both limestone and sandstone and may even include asphalt-impregnated sand. The content of included asphalt varies from less than 1 per cent to a maximum of perhaps 20 per cent, but a minimum of about 6.5 per cent asphalt is essential for paving use. However, rocks with 3 to 6 per cent asphalt are mined commercially, and either natural or oil by-product asphalt added to produce the required bonding qualities.

The commercial development of rock asphalt began in Europe shortly after 1800, and the first rock-asphalt pavement was laid in 1835. Important commercial deposits in Europe are in France (Departments of Ain, Haute Savoie, and Gard), Germany (Vorwohle and Escherhausen in Brunswick), Italy (Ragusa region, Province of Syracuse, Sicily), and Switzerland (Neuchâtel-Val de Travers region).

In the United States the most important producing deposits are in Texas, Oklahoma, Alabama, and Kentucky, but in 1946 production also came from California, Missouri, and Utah. Deposits also have been worked in Louisiana, Kansas, Arkansas, and New Mexico.

In *Texas* deposits of cocina limestone are worked near San Antonio, Ulvade County, averaging 9 to 12 per cent asphalt, to which petroleum asphalt may also be added. In *Kentucky* there are large deposits of asphaltic sandstone, some 20 to 60 ft thick, in Edmonson, Hardin, Breckinridge, Grayson, and several other counties. An average of 6.5 to 7.75 per cent asphalt is maintained, either as a natural product or by the addition of petroleum asphalt "flux." In *Alabama* both the limestone and sandstone types occur. Deposits have been described in Lawrence, Colbert, Morgan, and Franklin Counties in the northwest part of the state. Near Margerum the oölitic limestone produced contains 2.9 to 9.5 per cent asphalt. After crushing and blending it is fluxed with additional petroleum asphalt. In *Oklahoma*, in the Arbuckle Mountains in the south central part of the state, there are deposits of asphalt-impregnated sandstones, limestones, and occasionally shales containing 1 to 13 per cent asphalt. In *California* there are numerous large deposits of bituminous sands and sandstones in San Luis Obispo, Kern, Santa Cruz, Mendocino, and Ventura Counties. During the Second

World War the U.S. Geological Survey mapped the Edna, San Luis Obispo County, area and estimated reserves of 282,880,000 short tons to a depth of 250 ft, averaging about 11 per cent bitumen or 26 gal per ton. The Bureau of Mines worked out processes for extracting the bitumen by hot-water methods, anticipating possible use as a source of petroleum products.

Bituminous rock is nearly always mined by open-cut methods. The crude rock is crushed, ground to sand size, blended for uniformity, and if necessary mixed with additional asphalt flux. It is shipped in bulk in open-top cars or barges. It is used for the surface paving of highways, sidewalks, and floors; for lining tanks and reservoirs; and for roofing. For some uses, as for roofing, it is mixed with additional asphalt to produce a more easily worked mastic. It is a low-priced product, valued on an average, at only about \$3.50 to \$4.50 per ton at the mines. Recent statistics of production are given in Table 2.

Gilsonite, or uintaite, is an asphaltite characterized by the following physical properties. *Color*, black. *Fracture*, conchoidal (to hackly). *Luster*, bright to fairly bright. *Streak*, brown. *Specific gravity*, 1.05 to 1.10. *Hardness*, 2. *Melting point*, 250 to 350°F. It is found only in the United States, in a belt in the Uinta Basin about 65 miles long, extending from Rio Blanco County, Colo., into Uinta County, Utah, most of the important veins being in Utah.

The veins are more or less parallel, having a general strike of northwest to southeast. They vary in thickness from a few inches up to 18 or 20 ft and in length from a few miles to over 30 miles. They have been proved to a depth of over 900 ft in places. Branch veins joining the main veins at very acute angles are common. The walls, either of limestone or of shale, are nearly vertical and are often so impregnated with gilsonite for several feet that no sharp line of demarkation exists. Close to the walls the gilsonite has the characteristic columnar structure perpendicular to the walls that is common to all asphaltites. Near the outcrop gilsonite loses its brilliant luster and becomes a dull black through weathering.

Gilsonite is recovered by modern underground mining methods, hoisted in bulk, and sent to a cleaning plant. The crude material is separated into two fractions by screening at $\frac{1}{4}$ in. and passed over air cleaning tables to remove rock and fine grit. The finished product, separated into several grades based on size, quality, and mine source, is bagged and trucked 125 miles to Craig, Colo., the nearest rail point. The principal grades are known as "Bonanza" or "Eureka," Selects "L" or "M" ($+\frac{1}{4}$ in.), "S" ($-\frac{1}{4}$ in.), "Pulverized," and "Flour." Gilsonite from the Eureka mine differs somewhat in physical properties from that of the Bonanza mine.

The largest use for gilsonite is in the molding trade for making battery boxes and electrical accessories. Next in importance are asphalt floor tile, paint, and varnish. It is widely used in printing inks, particularly the brown rotogravure inks. Other uses are in rubber, electrical insulations, waxes, and acid-resistant paints and coatings.

Production statistics are given in Table 2.

Grahamite is a black asphaltite with the following physical properties. *Luster*, varying from dull to very bright. *Fracture*, conchoidal to hackly. *Streak*,

ASPHALTS, BITUMENS, WAXES, AND RESINS

black. *Specific gravity*, 1.15 to 1.20. *Hardness*, 2 to 3. *Melting point*, 350 to 600°F. It is found in many localities, having been first discovered and worked in Ritchie County, W. Va., but the largest vein in the world is in Jackfork Valley, 12 miles west of Tuscahoma, Okla. The vein here, 19 to 25 ft thick and a mile long, fills a fault in a shaley sandstone dipping at an angle of 37 to 50 deg. This deposit was once worked extensively, but production ceased many years ago.

Large deposits have been worked in Pinar del Rio Province, Cuba, and near San Fernando, Trinidad. Other deposits are known in Colorado, Texas, Mexico, and in Havana and Santa Clara Provinces, Cuba. In Neuquen Province, Argentina, on the eastern slope of the Andes, are several deposits of a bitumen somewhat intermediate in properties between grahamite, gilsonite, and impsonite. It has been produced under the name of *raphaelite*.

Grahamite finds little use today, but a few hundred tons per year are imported from Cuba. It is more difficult to melt and flux than gilsonite or other asphalts or asphaltites.

Glance pitch is an asphaltite intermediate between gilsonite and grahamite. It differs from gilsonite in having a higher specific gravity, a black streak, and in being less soluble in petroleum naphtha. A variety of glance pitch found in Barbados is known as "manjak," but this name is also applied to a variety of grahamite, having somewhat different properties, from Trinidad. These are both discussed under Manjak.

Glance pitch is found in Chapacote, Mexico; Barbados, Cuba; Colombia; Syria; and Egypt.

Manjak is a term that has been loosely applied both to glance pitch from Barbados and to a soft variety of grahamite from Trinidad. However, this distinction is more of technical than of practical interest, because the Trinidad grahamite approaches the Barbados glance pitch very closely in physical properties.

Barbados manjak has the following physical properties. *Color*, black. *Streak*, black. *Luster*, bright. *Hardness*, 2. *Fracture*, conchoidal. *Specific gravity*, about 1.1. *Fusion point*, 320 to 430°F. It contains about 90 per cent carbon, of which 25 to 30 per cent is fixed carbon, and has a solubility of 97 to 99 per cent in carbon disulphide.

Trinidad manjak has about the same properties, except that its specific gravity is 1.170 to 1.175; its melting point, 350 to 438°F; its carbon content, 84 per cent; and its fixed carbon content, 31.5 to 35 per cent.

Manjak has been used primarily for making paints and varnishes, particularly when mixed with mineral oils. It forms a tough, rubberlike coating, with a low viscosity, unaffected by acids, air, and water, and has a high heat resistance. As a pipe cement it has been found to be superior to white lead.

Elaterite. True elaterite is a very uncommon asphaltic pyrobitumen of scientific interest only, regarded by Abraham as a prototype of wurtzilite, with which it is often confused.

Wurtzilite, known popularly as "elaterite," is a black asphaltic pyrobitumen. *Fracture*, conchoidal. *Luster*, bright. *Streak*, light brown. *Hardness*, 2 to 3. *Specific gravity*, 1.05 to 1.07. Very thin slivers are semitransparent and show a

red color by transmitted light. It is sectile, cutting like horn or whalebone. Chips are somewhat elastic but snap like glass beyond the elastic limit. It is often called elastic bitumen or *mineral rubber*. It does not melt without decomposition, but softens and burns upon heating.

It is found in only one locality, in Uinta County, Utah, about 50 miles southwest of Fort Duchesne. More than 30 veins have been discovered, varying in width from 1 to 3 ft and in length from several hundred feet to about 3 miles. The largest of these veins have been and still are worked on a small scale.

Wurtzilite, sold commercially as elaterite, is used in making wurtzilite asphalt or wurtzilite pitch, which has been marketed under the name of "kapak." This is made by heating wurtzilite to 500 to 580°F under pressure, which causes it to depolymerize and markedly alters its physical properties. It is softer, fusible, readily soluble in carbon disulfide, and moderately soluble in naphtha of 88°F, whereas the crude is insoluble in both. Composition and properties vary with conditions of manufacture and it is marketed in numerous grades, either alone or mixed with gilsonite, asphaltic fluxes, or vegetable oils. Its uses are similar to those of gilsonite and grahamite.

Albertite is an asphaltic pyrobitumen mined originally in Albert County, New Brunswick, Canada, characterized principally by its infusibility and its insolubility in carbon disulphide, naphtha, etc. *Color*, black. *Streak*, brown to black. *Hardness*, 2. *Fracture*, conchoidal to hackly. *Luster*, dull to bright. *Specific gravity*, 1.07 to 1.10. It intumesces and decomposes upon heating.

It is found in Albert County, New Brunswick (deposits now exhausted); in Pictou County, Nova Scotia; Uinta County, Utah; and Tasmania, Australia. There is little or no present production.

WAXES AND RESINS

Ozokerite is a natural mineral wax, really a natural paraffin, but higher in melting point than commercial paraffin recovered from petroleum. *Color*, varies from nearly white through yellow and brown to dark green or black. *Streak*, pale brown. *Hardness*, less than 1 to 2. *Fracture*, conchoidal. *Luster*, dull to waxy. *Melting point*, 140 to 200°F. *Specific gravity*, 0.85 to 1.00. It is soluble in ether, petroleum, benzine, turpentine, and carbon disulfide.

The best known deposits are at Boryslaw, Galicia, near Lake Baikal, Siberia, and elsewhere in Russia; and in Utah at Soldier Summit, Wasatch County, and near Colton, Utah County. At Soldier Summit it occurs as a filling in brecciated zones in narrow fissure veins in sandstones and shales with a maximum wax content of about 15 per cent. Some of the Utah deposits were worked during the First World War, but they could not compete with the imported wax and have not been worked for many years. The wax was extracted with hot water (54 to 70°C) in steam-heated vats and purified by heating to remove entrapped moisture. In Galicia ozokerite has been distilled, yielding 39 per cent paraffin, 25 per cent petroleum, and 21 per cent lubricating oils. The residue, known as ozokerite pitch, was mixed with 60 per cent rubber and marketed under the name of okonite as an electrical insulating material.

Ceresine wax is made by the further refining of ozokerite with sulfuric acid and superheated steam.

Ozokerite and ceresine are used for many varied purposes: in cosmetics, acid-proof coatings, waxed paper, polishes, insulated wire and cable, and floor wax.

Montan wax is a wax of mineral origin derived from lignite. Chemically and in physical properties, including melting point, it resembles carnauba wax, except that it ranges in color from nearly white through brown to nearly black, instead of being light in color. Before the Second World War the United States imported millions of pounds annually from Germany and Czechoslovakia, then the only sources. Not all lignites are suitable raw material, but an extensive search during the war located several deposits in this country, containing 10 to 13 per cent recoverable wax that could be used, for example, near Malvern, Ark., and in California, the latter being the best. These deposits are located near Ione and Buena Vista, Calif., and a plant was built at Ione in 1948. By a solvent extraction process, not only is montan wax recovered, but also sap brown dye (used in paper) and vandyke brown pigment. The spent lignite, after a cleanup treatment, is briquetted for fuel or fortified with fertilizer as a combination fertilizer mulch and soil conditioner. Montan wax is used in carbon paper, polishes, rubber, phonograph records, roofing papers, wood impregnation, and for many other purposes.

Prewar imports averaged about 8,000 tons per year, mostly from Germany. Early in 1949 both the imported and the domestic product sold in the 30 to 34 cents per pound price range.

Coal Resins. Fossil resins, similar to the lac resins in appearance, composition, and properties, are found in bituminous coals in certain areas. In the Deer Creek and Salina Canyon coal districts of Utah these resins occur primarily along fracture seams in the coal, from less than $\frac{1}{8}$ to $\frac{3}{8}$ in. thick. In the better areas the resin content averages 5 to 7 per cent. Because of the mode of occurrence and the fact that the resin is much more brittle than the coal, satisfactory recoveries may be made by crushing as coarse as 6 to 8 mesh, leaving a coal product of marketable quality. In fact, the heating value is increased by the removal of the low Btu resin.

One production unit has been built at Huntington, Utah, using a sink and float system of recovery. A second plant at Bauer, Utah, with a reported capacity of 10 to 15 tons of coal-free resin per day, uses a froth flotation method of recovery. At the latter plant, described by Klepetko,⁴² the flotation concentrate, containing 75 to 80 per cent soluble resin, is refined by a solvent process using hexane (petroleum ether) as the preferred solvent. The pregnant liquors are filtered, freed from solvent, dried, remelted, and cast in drums.

The properties of the resin, as given by Klepetko, are as follows: *Specific gravity (melted)*, 1.03 to 1.06. *Acid number*, 6 to 8. *Softening point (mercury method)*, 160 to 165°C. *Iodine value (Wijs)*, 140 to 150. *Refractive index*, 1.544. *Color (Hellige, 25 per cent toluol)*, 14. *Molecular weight, average*, 732. *Purity*, 99 per cent plus pure hydrocarbon. The resin is very resistant to alkalies, water, and alcohol. It is completely miscible with both aliphatic and aromatic hydrocarbons and is compatible with vegetable and mineral oils, natural and synthetic

rubber, ester gum, phenolic and alkyd resins, and with such natural resins as kauri and copal. It is primarily competitive with the indene-coumarone resins and rosin. It is suitable for making electrical insulating and other varnishes, printing inks, waterproofing agents, special synthetic rubbers, and rubber cements. For the latter uses they are especially well adapted since they supply the essential tackiness lacking in synthetic rubbers.

Prices. In 1950, brilliant, first-quality gilsonite was quoted at \$36.50 per ton, fob Colorado; seconds, at \$31 per ton. Manjak was 6½ cents per pound, fob works in drums. Ozokerite was 18 to 30 cents per pound, depending on melting point and color. Montan wax, crude, was 31 to 32 cents per pound for domestic material and 26 to 27 cents per pound for imported.

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BARIUM MINERALS

Barite and Witherite

BARITE

Composition. Barite, also commonly known as barytes and heavy spar, has the formula BaSO_4 , its composition being BaO, 65.7 per cent; and SO_3 , 34.3 per cent. Commercial forms of barite may run as low as 92 per cent BaSO_4 with impurities consisting of silica, iron oxide, limestone, dolomite, shale, etc.

General Description. Barite is a heavy mineral, occurring most commonly (in commercial deposits) in granular or crystalline masses or nodules, usually light in color but sometimes brown or gray to nearly black. In typical museum specimens it is found in tabular, orthorhombic crystals.

Physical Properties. *Hardness*, 2.5 to 3.5. *Specific gravity*, 4.3 to 4.6. *Melting point*, infusible, but changes to BaO with high heat. *Index of refraction*, 1.636 to 1.648. *Color*, white to light shades of gray, blue, yellow, brown, or red. *Streak*, white. *Luster*, vitreous to almost resinous, or pearly; when granular almost earthy. *Cleavage*, two perfect at right angles, third indistinct. *Transparency*, transparent to opaque. *Tenacity*, brittle. *Insoluble* in water but soluble in concentrated sulfuric acid.

Occurrence. Geologically, barite has three main types of occurrence of importance commercially: (1) in beds or masses as replacements in limestones, dolomites, shales, and other sedimentaries; (2) as residual nodules resulting from the weathering of barite-bearing dolomite or limestone; and (3) as a gangue mineral in veins or beds with fluor spar, metallic sulfides, etc.

Deposits of barite are well distributed throughout the world; but until the start of its extensive use in oil-well drilling about 1926, important commercial development was confined to countries that were well developed commercially. Now, with widespread oil-well drilling all over the world, deposits are likely to be

developed in almost any favorable location. Barite is such a relatively low-priced commodity that production will be favored in those places which can show the lowest delivered cost in the principal markets. Thus, imported barite may be used along the Atlantic seaboard in spite of our large domestic productive capacity.

United States. For several years *Arkansas* has been the largest producing state. The entire production comes from the Magnet Cove area¹⁹ near Malvern, where a bedded, synclinal replacement deposit in shale is mined by two companies. Similar deposits have been explored west of Caddo Gap, Montgomery County.²⁰ This rock is an intimate mixture of barite, quartz, shale, and iron oxide, ranging in color from red and yellow through green to gray with a barium sulfate content of 50 to 85 per cent (average about 70 per cent). Although discovered by drilling in 1900 it had no commercial value until a successful froth flotation method was developed by the Bureau of Mines in 1939 and 1940. Impurities are so intimately mixed with the barite that the ore has to be ground to 100 per cent through 325 mesh for effective separation. By flotation methods it was shown that a 98 per cent pure barite could be made with specific gravity of 4.395 and a 90 per cent recovery. Reserves are stated to be around 9 million tons in the Malvern area.²³ Nearly the entire product is sold for well-drilling mud.

*Missouri,*³⁵ the second largest producer, has deposits in two general areas: Washington County and the central area. In both areas the barite occurs as nodules or large masses in a residual clay derived from dolomite by weathering. Most of the Missouri ore is of the soft variety, favored for the making of ground barite. Reserves in Washington County alone are stated to be about 20 million tons.²³

Georgia. For many years the largest producer, Georgia has been declining in importance for several years, due in part to exhaustion of deposits and in part to high costs of removing overburden. Practically all the production comes from the Cartersville district in Bartow County, where residual nodules in clay are mined by steam shovel. Most of the Georgia barite is of the hard, crystalline type used in the lithopone and barium chemical industries.

Tennessee. Production has come from the Sweetwater district (soft, residual nodules) and from the Del Rio, Cocke County, area (hard, crystalline barite mixed with fluorspar in veins).

*Nevada*⁹ has become an increasingly important producer in the last 10 years. Deposits are known in at least nine counties, but at present important production is centered in the Argenta-Battle Mountain area in Lander and Eureka Counties on both sides of the Humboldt River in northern Nevada. Both vein and replacement deposits occur, the former usually having white barite, and the latter usually gray to black. One producer reports reserves of 2.5 million tons in three deposits in the Battle Mountain area.²³ Chief uses for Nevada barite are for oil-well muds and for making barium chemicals in a California plant.

California. While barite deposits have been noted in at least eight counties in California, most deposits have not proved very extensive. In 1946 only two or three mines were in operation, one near El Portal, Mariposa County (50,000 tons

reserves),²³ and the Spanish mine near Washington, Nevada County (200,000 tons reserves).²³ Two more mines were reported to be starting production in 1945, one near Greenville, Plumas County, and the other near Auburn, Placer County. The former was reported in operation in 1946. At the El Portal mine¹⁸ witherite and barite occur together and are mined and processed together.

*Arizona.*¹⁸ Small, irregular shipments of barite were made from Arizona in earlier years, but in 1946 production began on a larger scale from a vein deposit at Coon Bluff, 22 miles northeast of Mesa. The ore, from veins up to 15 ft wide, is crushed and wet-ground to 200 mesh to make a product with about 94 per cent barite and a specific gravity of 4.0 or more. The addition of a flotation department in 1947 has been reported.

Other states from which there has been some production in the past or in which are reported deposits of possible commercial interest are Virginia, North Carolina, South Carolina, Idaho, New Mexico, Wisconsin, Alabama, Texas, Colorado, Kentucky, Connecticut, and Massachusetts. No production was reported from any of these states in 1946, but several of them have been small producers within the past ten years. Late in 1947 it was reported that a new deposit was being opened near Hailey, Idaho, and a flotation plant was being built near Pocatello.

Germany. Prior to the Second World War Germany was the world's largest producer of barite, accounting for over 50 per cent of the world's production. What its postwar position will be cannot be predicted, but it is probable that it will again become an important factor in the world picture. "Barite occurs in bedded deposits at Meggen in Westphalia and in veins in Hessen, Thuringia, Bavaria, Baden, and Silesia. The Meggen deposits are the most productive, yielding in the average from 65 to 75 per cent of the total German output."² Exports to the United States, mostly from Meggen, were shipped to the Rhine via canal, thence by barges to Rotterdam, and from there by ship to this country.

Canada. Canadian production of barite was unimportant until the discovery in 1940 of a very large deposit at Pembroke, Hants County, Nova Scotia, on the Bay of Fundy.^{5,6} A mill was built at Walton in 1941 and production quickly rose to about 114 thousand net tons per year in 1945 and 1946. This deposit, over 100 ft thick, 200 ft wide, and over 600 ft long, of medium grain, with crystalline texture, and reddish in color, is 96 to 98 per cent pure, with an average specific gravity of about 4.4. While its chief markets at the start were for oil-well drilling in Trinidad and South America, sizeable shipments to United States barium chemical producers have been made, beginning in 1944. Other Canadian production has come from the Nighthawk Lake area of the Porcupine mining district in northern Ontario and from a small deposit at Parson, British Columbia.

*Brazil.*²¹ The large demand for barite for well-drilling mud in Venezuela, Colombia, and Trinidad caused the opening of a large deposit of barite on the island of Camamu, off the coast of Brazil, 80 miles south of Salvador, Baia, in 1945 and 1946. With United States capital a grinding mill was built and a 97.5 per cent minus 300-mesh product, running 92.5 per cent barite, 4.3 specific gravity, is bagged and shipped. Plant capacity is 42 thousand tons per year, and reserves are over 1 million tons.

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*United Kingdom.*⁷ England and Wales are important producers of barite and witherite. In 1945 six barite mines were operated in a belt extending from the Tyne Valley of Northumberland southward through parts of Durham, Cumberland, and Westmoreland to the Craven district of West Yorkshire. Two producers were in the coal fields of Northumberland and Durham and other deposits were worked elsewhere in England and Wales.

TABLE 1. WORLD PRODUCTION OF BARITE, 1942 TO 1948, BY COUNTRIES, METRIC TONS¹
(Compiled by B. B. Mitchell)

Country ^a	1942	1943	1944	1945	1946	1947	1948
Algeria.....	2,753	2,988	1,340	.....	14,240	23,692	16,681
Argentina.....	7,083	11,009	b	.....	10,000	35,000 ^c	b
Australia.....	6,512	4,610	4,487	3,502	7,708	5,500	b
Austria.....	b	b	b	b	808	2,007	3,842
Belgium.....	550	170	300	.....	b	b	b
Brazil.....	240	b	282	617	10,326	13,971	10,000 ^c
Canada.....	17,842	22,202	107,700	126,632	109,242	116,731	86,608
China ^e	18,000	b	b	b	b	b	b
Cuba.....	3,787 ^d	3,158 ^d	4,787 ^d	2,094 ^d	b	b	b
Egypt.....	60	76	59	54	b	167	b
Eire.....	b	5,485	10,519	16,714	13,557	12,904	b
France.....	9,563	18,290	9,575	11,431	34,570	50,275	b
Germany:					45,736 ⁱ	35,000 ⁱ	41,000 ⁱ
Baden.....	44,156	340,000	320,000	b	i	i	i
Bavaria.....	27,537				i	i	i
Prussia ^e	258,602				i	i	i
Saxony.....	25				i	i	i
Thuringia.....	9,357				i	i	i
India.....	11,462	9,002	15,545	25,051	29,558	24,700	15,425 ^d
Indochina.....	100	.....	.....	b	b	b	b
Italy.....	37,601	.....	b	b	24,861	65,798	56,000 ^c
Japan.....	15,345 ^f	15,642 ^f	12,049 ^f	7,540 ^f	581	907	3,334
Korea (Chosen).....	11,693	10,099	5,640	b	100 ^c	1,000 ^c	*
Peru.....	b	.....	2,352	4,240	b	7,000 ^c	b
Portugal.....	b	1	b	.....	294	1,211	b
Southern Rhodesia.....	2,675	1,256	13	.....	173	18	51
Spain.....	7,801	6,309	7,491	9,877	12,245	21,028	15,968
Swaziland.....	.....	.....	.....	79	224	172	98
Switzerland.....	256	268	233	.....	b	b	b
Tunisia.....	.....	72	76	68	408	470	230
Union of South Africa...	745	2,740	3,201	2,209	2,326	2,672	1,734
United Kingdom ^g	100,312	102,736	100,422	94,711	112,705	96,267	b
United States.....	408,116	389,451	467,321	628,068	657,908	802,146	705,642

^a In addition to the countries listed, barite is produced in Czechoslovakia, Greece, Mexico, Norway, U.S.S.R., and Yugoslavia, but data on production are not available.

^b Data not available.

^c Estimate.

^d Exports.

^e Official figures which, it is reported, cover only output of mines included under the mining law.

^f Preliminary data for the fiscal year ended Mar. 31 of year following that stated.

^g Includes witherite.

^h Excludes British Zone.

ⁱ Excludes British, French, and Soviet Zones.

^j Included in Germany.

^k South Korea only.

Other Countries. Italy, in prewar years, produced 40 to 50 thousand tons of barite per year. During the Second World War a deposit of barite was opened near La Rosita, Coahuila, Mexico, and shipments made to the United States for lithopone. Table 1 shows other producing countries of lesser importance as reported by the U.S. Bureau of Mines.

Production and Consumption. Tables 2 and 3, from the "Minerals Yearbook" of the U.S. Bureau of Mines, show the production and indicated consumption of barite and barium products in the United States.

TABLE 2. SALIENT STATISTICS OF THE BARITE, WITHERITE, AND BARIUM-CHEMICAL INDUSTRIES IN THE UNITED STATES, 1944 TO 1948

	1944	1945	1946	1947	1948
Barite:					
Primary:					
Produced, short tons.....	515,136	692,330	725,223	884,129	777,841
Sold or used by producers:					
Short tons.....	518,617	696,062	724,362	843,082	799,848
Value:					
Total.....	\$3,558,489	\$5,348,652	\$5,242,755	\$6,172,342	\$6,693,413
Average.....	\$6.86	\$7.68	\$7.24	\$7.40	\$8.37
Imports for consumption:					
Short tons.....	67,888	56,894	44,662	53,222	53,204
Value:					
Total.....	\$459,664	\$382,611	\$274,267	\$378,294	\$443,515
Average.....	\$6.77	\$6.72	\$6.14	\$7.11	\$8.34
Apparent new supply, short tons	586,505	752,956	769,024	887,304	853,052
Domestic, per cent.....	88.4	92.4	94.2	94.0	93.8
Reported consumption, short tons.....	595,563	720,903	722,073	835,818	894,309
Ground (and crushed):					
Sold by producers:					
Short tons.....	344,757	468,939	455,240	549,965	631,424
Value.....	\$5,455,835	\$7,519,759	\$7,208,193	\$8,979,400	\$11,195,365
Imports for consumption:					
Short tons.....	11,964	1		a	a
Value.....	\$243,917	\$15		a	\$11
Witherite (crude):					
Imports for consumption:					
Short tons.....		896	1,107	739	2,470
Value.....		\$26,736	\$31,599	\$25,757	\$94,809
Barium chemicals:					
Sold by producers:					
Short tons.....	73,591	68,084	80,871	72,919	71,717
Value.....	\$7,740,686	\$6,493,448	\$7,003,756	\$7,035,104	\$7,028,058
Imports for consumption:					
Short tons.....	95	35		72	152
Value.....	\$7,382	\$3,098	\$58	\$11,448	\$23,263
Lithopone:					
Sold or used by producers:					
Short tons.....	142,905	136,161	147,001	165,024	140,033
Value.....	\$11,208,891	\$10,645,316	\$11,840,596	\$17,382,592	\$16,135,976
Exports of lithopone:					
Short tons.....	11,551	11,576	9,651	13,652	21,015
Value.....	\$1,107,430	\$1,049,961	\$888,555	\$1,784,414	\$2,972,912

* Data not available.

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TABLE 3. DOMESTIC BARITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1946 TO 1948, BY STATES

State	1946		1947		1948	
	Short tons	Value	Short tons	Value	Short tons	Value
Arkansas.....	288,286	\$1,844,982*	376,017	\$2,390,643	362,470	\$2,899,760
Georgia.....	69,274	686,583	61,202	639,865	62,781	654,959
Missouri.....	270,850	2,168,067	291,619	2,405,249	278,071	2,413,802
Nevada.....	†	†	37,388	261,168	†	†
Tennessee.....	33,595	272,169	31,476	285,853	25,818	275,242
Other states†.....	62,357	270,954	36,380	188,564	70,708	449,650
	724,362	\$5,242,755	834,082	\$6,171,342	799,848	\$6,693,413

* Partly estimated.

† Included under "Other states."

‡ 1946 and 1948: Arizona, California, and Nevada; 1947: Arizona and California.

No data are available on world consumption by uses. Before the use of barite for oil-well drilling mud only highly industrialized countries were important users of barite in any form, but today important consumption tends to follow oil-well drilling all over the world.

Mining and Milling. *Mining methods* used in the barite industry vary widely with the type and size of deposit and type of product made. Harness and Barsigian¹³ have given the best recent brief summary of mining methods, from which this section has been taken in part. In general, five methods of recovering barite have been used in recent years.

1. Residual barite in clay is dug with power shovels from open pits (Missouri, Tennessee, Georgia). Stripping, when light or when it contains some barite, may be ignored, and the whole body mined together; when heavy it is removed by dragline, tractors, and scrapers or power shovel. Overburden in Missouri is rarely over 2 or 3 ft, but in Georgia it may range from 10 to 50 ft. Hydraulic mining has been used at times in Georgia where overburden has been heavy, where troublesome limestone pinnacles have been encountered, or where tailings ponds have been reclaimed. Ore is hauled to mills by trucks (or pumped where hydraulic mining is used).

2. Barite-bearing shale is blasted from open pits (Arkansas, in part).

3. Barite veins or beds are mined underground (California, Nevada, Tennessee, and Arkansas, in part).

4. Massive barite is blasted from open quarries with little or no subsequent sorting or beneficiation (Nevada).

5. Residual deposits are mined by hand (Missouri). Hand mining, once predominant in Missouri, is now of minor importance.

Milling Methods.¹³ Methods used in the beneficiation of barite depend both on the nature of the ore and on the type of product to be made. For the largest use, well-drilling mud, the only requirements are fine grind (325 mesh), chemical inactivity, and high specific gravity. White color is not essential, and purity is

not important except as it reflects specific gravity. Where most of the output is sold for this use the product may need to be only ground and bagged, except in the unusual case of the Arkansas ore, which will be discussed later.

The essential features of the milling of residual barite in clay (Missouri, Georgia, and Tennessee, in part) include washing to remove the clay, hand picking to save lump barite, jigging to separate coarse concentrates, and tabling to recover fine concentrates. Further refinements may include magnetic separation to remove iron from fine concentrates and froth flotation to save the very finest barite. In Missouri, where the ore is so soft that crushing is unnecessary and individual deposits tend to be small, simple, inexpensive plants that can be easily dismantled and moved are common. In Georgia the ore is hard and usually must be crushed to free the barite from the gangue; plants tend to be larger with several stages of crushing, screening, jigging, and tabling.

Hale,¹⁰ in discussing the milling of Georgia barite, gives the generalized flow sheet of a mill of moderate complexity shown in Fig. 1. In the magnetic separating plant the ore is dried, crushed to 12 mesh, and fed to two magnetic separators, which make concentrates with less than 0.7 per cent iron and a small tailings product with 25 per cent barite and 45 per cent iron. He also shows a more elaborate mill, with more jigs and tables, regrinding jig middlings before tabling.

Missouri mills may consist essentially of only a double log washer, trommel, and jigs, but there are a few larger mills.

Hard, vein barite is usually pure enough to be shipped without beneficiation except by hand sorting.

The development of successful froth flotation methods for barite^{16,17,18,22,23,24} made deposits such as those of Arkansas commercially valuable and greatly increased recovery possibilities from other deposits. The Arkansas ore is particularly difficult to treat, since the barite is so finely divided and so intimately mixed with the impurities that grinding to 100 per cent —325 mesh is necessary for complete liberation of the component minerals. The two mills now processing this ore have not made public the details of their processes, but it is reported that they both wet-grind in ball mills to nearly all —325 mesh. The ground ore is treated by froth flotation, one mill floating the barite and the other depressing it. Concentrates are filtered and dried in rotary kilns at temperatures high enough to destroy organic reagents that might interfere with use in drilling muds. In Georgia flotation is being used to recover barite fines from washer tailings.

Ground Barite. Methods used in grinding barite depend upon the nature and condition of the product to be ground and upon the use for which the ground barite is to be sold. Where ore must be fine-ground for flotation or where wet-milled products such as jig concentrates are to be ground, fine grinding is usually done wet. If white color is not important, as for well-drilling mud and off-color filler uses, iron grinding surfaces may be used, ball mills for wet grinding being used in Arkansas and five-roller Raymond mills for dry grinding in Georgia. Where the color is naturally a good white and no bleaching is required grinding should be done with iron-free grinding surfaces, such as a wet pebble mill in closed circuit with a classifier or a dry pebble mill in closed circuit with an air separator.

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For dry grinding the feed should be dried, either naturally or artificially. Wet-ground products must be thickened, filtered, and dried.

When the product is to be bleached the barite is wet-ground in pebble mills, thickened, bleached, filtered, dried, reground, and bagged. Details of bleaching

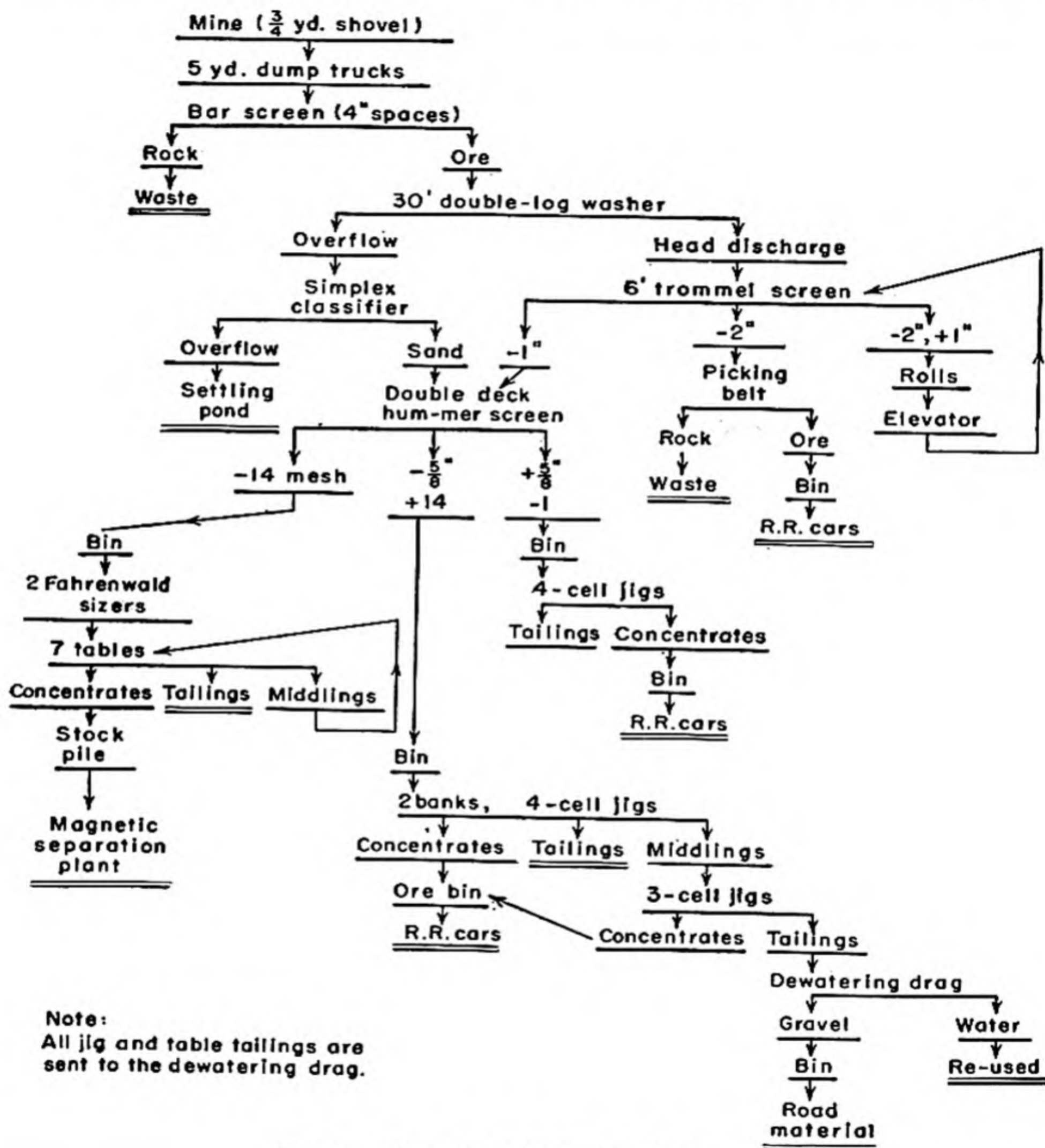


FIG. 1. Flow sheet of Georgia barite mill.

methods are generally held as trade secrets, but the general principles are well known. The thickened sludge is treated in lead- or ceramic-lined bleaching tanks with hot, dilute sulfuric acid. The charge is agitated continuously, either with live steam or mechanically, for 8 to 12 hr. Acid temperature may be around

212°F. Time, temperature, and acid strength must be adjusted to the ore being treated. After treatment the barite must be washed very thoroughly to remove the last traces of ferrous sulfate. If this is not done the ferrous sulfate is oxidized during drying and gives the product a yellowish-brown color. The addition of a small amount of sulfurous acid to the final bleached pulp is claimed to assist in overcoming this difficulty. Missouri barite, due to its softness, is favored for making bleached, ground barite.

Fineness of grind for most filler uses varies from 95 to over 99 per cent through 325 mesh. For glassmaking a coarse, granular product is desired: 16 to 20 mesh, with a minimum of -200 mesh.

Marketing, Shipping, and Prices. Barite is marketed in the following forms: crude, hand-selected lump; jig and table concentrates; granular (for glass trade); fine-ground for well-drilling mud; fine-ground bleached; and fine-ground off-color for filler.

Crude barite is sold on the ton basis, fob cars mines, and may be shipped in open-top or boxcars. Bleached ground barite is usually packed in 50-lb paper bags, and all other ground barite in 100-lb bags.

Nevada and California barite is sold chiefly in California for oil-well drilling and for lithopone and barium chemicals. Arkansas barite is used chiefly in the Gulf Coast oil fields, but to some extent in glass plants in the Middle West. Missouri barite is largely consumed in making titanium pigments, lithopone, and barium chemicals in St. Louis and in Illinois and Kansas, but some is sold for well drilling in the Gulf area. The logical markets for Georgia and Tennessee barite are in the barium chemical and lithopone plants in West Virginia, Maryland, Delaware, New Jersey, and Pennsylvania, but imported barite from Nova Scotia and Germany, competing for Atlantic Coast markets, sometimes forces southern barite into Illinois markets. Nova Scotia barite has gone largely to well drillers in the West Indies and South America, but increasingly it is being shipped into our Atlantic coast markets.

Crude barytes ore was quoted at \$11.50 to \$12.00 per long ton in 1950 in Georgia. In Missouri, crude ore, minimum 94 per cent barite and less than 1 per cent iron, was quoted at \$9.40; 93 per cent barite, at \$9.00 to \$9.15 per ton. Water-ground, floated, and bleached, it was quoted at \$35.10 per ton in carload lots fob works.

Barium chloride, technical grade, is quoted at \$85 per ton in carload lots. Most barium compounds are sold by the pound. Lithopone is priced at \$0.0625 per pound.

Specifications* and Tests. No generally accepted standard specifications or tests for either crude or ground barite are now in use. In the trade two general types of crude ore are recognized: the "soft" ore and the "hard crystalline" ore. The soft ore can be easily crumbled and is preferred by the grinders, since it is more easily ground and bleached and is also said to roast better. The hard crystalline ores can be used to better advantage in the lithopone and barium chemical industries. Commercial crude barite should contain not less than 93 per cent barite; the better grades contain 95 to 98 per cent barite and 1 to 3 per cent silica.

* The best recent discussion of specifications and uses is by Harness and Barsigian.¹³

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Ground barite is marketed in several grades, dependent on color and fineness, from the coarse-ground off-color product to the very fine-ground, pure-white, water-floated product. When used as a filler for paper or rubber, it must be at least 200 mesh and is often 350 mesh—the finer the better. For the paint trade a pure-white product is needed, but extreme fineness is not always desired; in fact, extremely fine-ground barite is said to be unsuitable for some paint purposes.

For well-drilling mud barite must have a high specific gravity (4.2 or better is usually specified) and be chemically inert. Soluble salts, including gypsum, tend to flocculate bentonite used in muds. Barium carbonate (witherite) and iron oxide are not detrimental if the specific gravity is maintained, although usually a minimum barite content of 92 per cent is sought.

For glassmaking a granular product is specified, running all through 20 mesh with a minimum of minus 200-mesh dust. As with all ceramic raw materials, fine dust tends to "ball up" into aggregates that are difficult to melt. Low iron (maximum 0.2 per cent ferric oxide or less) is essential, and a minimum of 98 per cent barite may be specified.

For making lithopone and barium chemicals, soft barite has been preferred in the past, but now the hard, crystalline type is used extensively. Fluorine is harmful and only small traces are allowed. A typical buying specification calls for 94 per cent barite minimum with 1.0 per cent ferric oxide maximum. This may be combined with a premium and penalty clause paying a premium of 25 cents per ton for each per cent of barite above 94 per cent and 25 cents per ton for each 0.1 per cent ferric oxide below 1.0 per cent, with similar penalties for lower barite and higher ferric oxide content. Barite content below 92 per cent is generally not acceptable for these uses even with penalties. The premium-penalty system is not so general in Georgia and Tennessee as it is in Missouri. All analyses are made on a dry basis. Buyers in Missouri often assume an average moisture content of 5 per cent and deduct for this amount from the purchase price.

TABLE 4. CRUDE BARITE (DOMESTIC AND IMPORTED) USED IN THE MANUFACTURE OF GROUND BARITE AND BARIUM CHEMICALS IN THE UNITED STATES, 1944 TO 1948, SHORT TONS

Year	In manufacture of			Total	Year	In manufacture of			Total
	Ground barite*	Lithopone	Barium chemicals			Ground barite*	Lithopone	Barium chemicals	
1944	360,045	134,597	100,921	595,563	1947	561,230	167,321	107,267	835,818
1945	482,442	139,288	99,173	720,903	1948	640,284	153,987	100,038	894,309
1946	465,468	154,166	102,439	722,073					

* Includes some crushed barite.

Utilization.¹³ The uses for barite may be divided into three general groups: ground barite, lithopone, and barium chemicals. The division of production by uses is given in Table 4, after the U.S. Bureau of Mines.

Ground Barite. The distribution of sales of ground barite by principal end uses is given in Table 5, after the U.S. Bureau of Mines.

By far the largest single use of barite is for oil-well drilling mud. In wells that encounter excessive gas and oil pressures there is danger of blowing out the well when these pressures exceed the pressure of water in the well. To counteract this danger and for other reasons¹⁹ it has long been the practice to increase the weight of the water column by adding clay, suspended with bentonite, to the drilling fluid. But clay is comparatively light in weight and too much clay unduly increases the viscosity of the fluid. In order to increase weight still more, ground minerals of high specific gravity were tried, among them iron oxide, barite, and celestite. Barite, due to its low cost, high specific gravity, cleanliness, inertness, and freedom from impurities, has become the standard weighting material. Its use was long controlled by patents²⁰ which have now expired. About 5 tons of barite is consumed for each 1,000 ft of high-pressure well drilled.

TABLE 5. GROUND AND CRUSHED BARITE SOLD BY PRODUCERS, 1946 TO 1948, BY CONSUMING INDUSTRIES*

Industry	1946		1947		1948	
	Short tons	Per cent of total	Short tons	Per cent of total	Short tons	Per cent of total
Well drilling.....	372,610	82	467,350	85	565,249	90
Paint.....	26,000	6	33,641	6	23,580	4
Glass.....	29,181	6	29,000	5	22,000	3
Rubber.....	20,000	4	17,000	3	18,000	3
Undistributed.....	7,449	2	2,974	1	2,595	^a
	455,240	100	549,965	100	631,424	100

* Barite used in chemicals, although crushed before use, is not included in 1945 and 1946 totals. In 1944 and prior years small quantities of crushed barite used by chemical producers are included.

^a Less than 0.5 per cent.

Other important uses for ground barite are as inert mineral fillers in paper, rubber, cloth, linoleum, oilcloth, etc., and as a paint material, both as a white pigment and as an inert extender. It is especially useful as a filler and a surfacing material for playing cards, enameled paper, oilcloth, etc., where a highly calendered surface is desired. It is also used as a filler in making artificial ivory and buttons; as a base for the precipitation of lake colors; in ceramic glazes and enamels; and as an inert filler and body material for many miscellaneous products where a heavy, crystalline filler is desired.

In glass, granular barite is used as a flux, a deoxidizer, and a decolorizer, making the melt more workable and increasing the brilliance of the glass. Carbon or zinc dust is added to the batch as a reducing agent. Amounts used are 4 or 5 lb of barite per 100 lb of glass sand. In making window and container glass in continuous tanks barite may replace salt cake formerly used as surface flux.

Lithopone, also known by the trade names Ponolith, Beckton White, Marbon White, Zincolith, Sterling White, B-J White, and Grasselli White, is a white pigment consisting of approximately 70 per cent barium sulfate and 30 per cent zinc calculated as zinc sulfide. The zinc sulfide is usually replaced by 1 to 3 per

BARIUM MINERALS

cent zinc oxide. The European brands contain zinc sulfide in amounts varying from 11 to 42 per cent. The commercial product is a very fine-grained white powder, 98 to 99 per cent or more of which will pass through a 325-mesh screen.

Chart 2 (Fig. 2) shows briefly the method of lithopone manufacture.

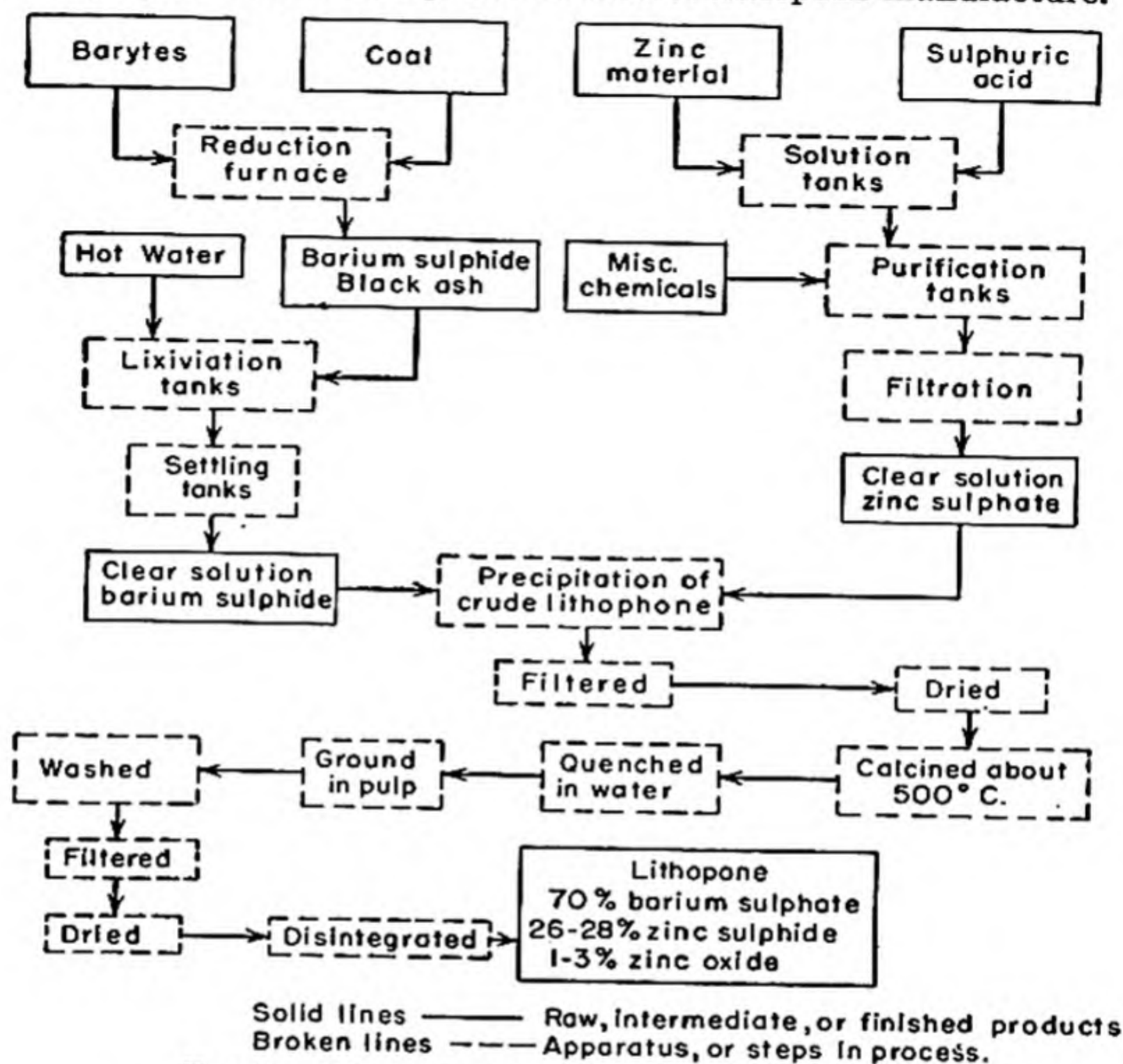


FIG. 2. Diagram of the manufacture of lithopone.

To manufacture a ton of lithopone 1 to 1¼ tons of barite and a total of about 4 tons of all raw materials, such as zinc, barite, sulfuric acid, coal, etc., are required.

In 1946 lithopone was manufactured in eight plants in the United States.

Lithopone is used extensively in the manufacture of paints, both as a white pigment alone and mixed with other pigments. Another very large use is in the manufacture of high-grade rubber goods, such as automobile tires, rubber matting, fruit-jar rings, tubing, etc. In rubber it not only acts as a filler but also is valuable for the curative effect that the zinc sulfide has on the rubber. It is also used as a filler in oilcloth, linoleum, window-shade cloth, etc., and to a smaller extent in printer's ink and face powder. As a pigment it has long been popular in flat wall tints, but now grades have been developed that are suitable for outside work.

Table 6 shows the distribution of lithopone by end use in the United States in recent years (after the U.S. Bureau of Mines).

Barium Chemicals. In 1948 there were 20 plants in the United States making barium chemicals. Their total production amounted to nearly 71,000 short tons,

valued at over 7 million dollars. This production was greater than in 1942 and greater than for any war year in spite of the fact that barium nitrate production, used almost wholly for war materials, is an important tonnage item.

TABLE 6. LITHOPONE* SOLD OR USED BY PRODUCERS, 1946 TO 1948, BY CONSUMING INDUSTRIES

Industry	1946		1947		1948	
	Short tons	Per cent of total	Short tons	Per cent of total	Short tons	Per cent of total
Paints, enamels, and lacquers.....	123,279	84	134,830	82	104,441	75
Floor coverings and textiles.....	15,167	10	17,469	10	20,859	15
Rubber.....	1,607	1	3,085	2	4,192	3
Other.....	6,948	5	9,640	6	10,541	7
	147,001	100	165,024	100	140,033	100

* Exclusive of cadmium lithopone.

The principal barium chemicals, in approximate order of present production, are as follows.

Barium carbonate (nearly 27 per cent of 1946 tonnage) is now used chiefly for brick descumming, oil-well drilling, and case-hardening compounds for steel and optical glass.

Precipitated barium sulfate or blanc fixe is the best grade of barium sulfate for pigment purposes, both in whiteness and in fineness of product. In chemical composition, blanc fixe is practically identical with natural-ground barite, but its physical properties are different. The two products should not be confused. Blanc fixe is largely used where a pure-white pigment or filler is desired, as in paints, rubber goods, linoleum, oilcloth, and glazed paper. It is also used in lithographic inks as a base for lake colors. Blanc fixe, under the name of chemically pure barium sulfate, is used as an indicator in X-ray photography. It is placed on the market as a pulp and as a dry powder. The pulp is a paste containing about 30 per cent water and is used chiefly by the paper and lithographic ink manufacturers. The dry powder is used for pigment purposes. It is made as a direct product by reacting a soluble barium salt, such as the sulfide, with sodium sulfate. A slightly lower grade is made as a by-product in making hydrogen peroxide from barium peroxide.

Barium nitrate is used chiefly in green signal flares and in primers and detonators.

Barium chloride is used in case-hardening steel, as a mordant in textiles, in precipitating blanc fixe in place in leather and textiles, and in many chemical processes.

Other barium chemicals of some importance are the oxide, peroxide, and hydroxide, but there are numerous barium chemicals of minor importance.

Barium-titanium pigments are noted and described under Titanium Minerals. The methods of manufacture of barium chemicals have been well covered by

BARIUM MINERALS

Harness and Barsigian.^{12,13} Since barite is so very insoluble in water the first step in making barium chemicals is usually that of converting to a water-soluble form. The classic method of doing this is to roast ground barite with carbon in the form of pulverized coal or petroleum coke, making a product called *black ash*, which is an impure form of the soluble salt barium sulfide. From black ash a solution of barium sulfide may be prepared, which, after purification, may be reacted with acids or other soluble salts to yield the barium compounds of commerce. The reactions are complicated and many special processes have been patented.¹³

WITHERITE

Composition. Witherite is barium carbonate, BaCO_3 (BaO, 77.7 per cent; CO_2 , 22.3 per cent).

General Description. Witherite is a heavy, white or gray, translucent mineral occurring as masses of indistinct crystals; it is also granular, columnar, or in twinned orthorhombic crystals. It is found in veins, usually with barite or ores of lead or silver.

Physical Properties. *Hardness*, 3 to 4. *Specific gravity*, 4.2 to 4.35. *Melting point*, 2.5 to 3 in scale of fusibility. *Index of refraction*, 1.529 to 1.677. *Color*, white, gray, yellowish, or colorless. *Streak*, white. *Luster*, vitreous to greasy. *Cleavage*, imperfect prismatic, fracture uneven. *Transparency*, translucent to transparent. *Tenacity*, brittle.

Occurrence and Production. Occurs with galena in various deposits in northwestern England, as at Fallowfield in Northumberland, Duxton in Westmoreland, and Alston Moor in Cumberland; also with barite at Freeburg, Saxony. The most important mines are located near Hexham, Northumberland County, England. The mineral is found in large lenses in galena-bearing veins, which were mined by the Romans in the first century A.D. The most important producer has been the Settlingstones mine. Witherite is found in a vertical vein in widths of up to 10 ft. The most productive zone is located between the 500- and 800-ft levels. The ore is hand picked, and a selected concentrate containing 94 per cent or more barium carbonate is assembled for shipment to market. Lower grade material is crushed and beneficiated by jigging and other modern treatment, and a satisfactory concentrate obtained. Part of the production is exported to Philadelphia, where it is prepared for the American trade. It is sold as lump, coarse granular, and air-floated powder. The latter product was quoted at \$65 per ton in carload lots in 1948.

United States. Small amounts of witherite have been reported near Lexington, Ky., and in the Thunder Bay district of Lake Superior. Possibly the largest known tonnage is located near El Portal, Calif. It is closely associated with barite and is mined with it and ground in the preparation of oil-well drilling muds without separation. Therefore, the actual tonnage production is not known.

Utilization. Because of its solubility in common acids witherite is a favored material for the preparation of barium salts for chemical use. It is used to introduce carbon in the surface of steel in the case-hardening process, its most important use; in sugar refining; and in the manufacture of heavy clay products, enameled iron, and glass.

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BAUXITE*

Definition and Composition. The U.S. Bureau of Mines gives the following definition: "The term bauxite is defined as being an aggregate of aluminous minerals, more or less impure, in which the aluminum occurs largely as hydrated oxides." Theoretical bauxite has been given the formula $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ or $\text{Al}_2\text{O}(\text{OH})_4$, but most authorities agree that bauxite is not a distinct mineral.

* Since nearly 80 per cent (1946) of the bauxite consumed in this country is for making metallic aluminum and is not a nonmetallic mineral, only a brief summary will be given here.

Commerical bauxite is commonly composed of two or perhaps three aluminum hydrates plus silica, iron oxide, titanium oxide, clay, and other impurities. The three hydrates are diaspore, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$; theoretical bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$; and gibbsite, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, the last being the most common. Theoretical bauxite contains 73.9 per cent Al_2O_3 (39.2 per cent aluminum) and 26.1 per cent H_2O . Commerical ore today contains 48 to 65 per cent Al_2O_3 .

Laterite is a geologic term applied to partly consolidated materials, such as siliceous and ferruginous bauxites, siliceous and aluminous iron ores, and manganese ores, formed by surface weathering of igneous rocks such as basalts.

General Description. Bauxite is an earthy mineral, never crystallized, occurring in a variety of forms and colors. It often shows a pisolitic or oölitic structure with rounded concretionary grains embedded in an amorphous or claylike mass. The pisolites vary in size from a small fraction of an inch to as much as 2 in., but usually average from $\frac{1}{4}$ to $\frac{3}{4}$ in. They also occur as hard or soft structureless amorphous masses. Some bauxites are regarded as decomposition products of feldspathic rocks, such as granites, syenites, and gneisses, but others are supposed to be derived by solution of alumina from sedimentaries, such as shales, followed by deposition from solution as grains, nodules, and irregular pockets in limestones and dolomites.

Physical Properties. *Hardness*, 1 to 3. *Specific gravity*, 2.55. *Melting point*, changes to Al_2O_3 , which, when pure, melts at 1880 to 2050°C. *Index of refraction*, 1.57. *Color*, white, cream, yellow, brown, gray, or red. *Streak*, variable. *Luster*, dull to earthy. *Cleavage*, irregular fracture. *Transparency*, opaque. *Tenacity*, crumbly.

Occurrence. The geological occurrence of bauxite varies greatly in different localities. Thus, the Arkansas ores are found in bedded deposits derived from syenites by alteration and by replacement of silica by alumina. The Georgia deposits are regarded as being derived by solution of alumina from shales, transportation upward by ascending solutions, and deposition as irregular bodies in dolomite and limestone. The occurrence of the bauxites of Alabama and Tennessee is similar to that of the Georgia ores. The bauxite deposits of Vogelsberg, Germany, are bedded deposits supposed to be derived from basalt by decomposition in place.

Known deposits of high-grade bauxite of large size are not common. In only a few areas in the world have such deposits been developed. The United States, once the world's largest producer, had dropped to sixth place by 1940, due to exhaustion of the richest deposits and to lower cost of imported material. Because of war conditions and the very large demand for aluminum, domestic production increased enormously, and from 1943 to 1945 this country was again the largest producer, but much lower grade bauxite was produced than would have been acceptable in prewar years. The world's largest producing countries during the war years were the United States, British Guiana, Surinam (Dutch Guiana), Hungary, Italy, France, and Russia.

United States. Arkansas accounts for nearly 95 per cent of the domestic production of bauxite. Practically all of it comes from two areas totaling perhaps 15 square miles in Saline and Pulaski Counties in the central part of the

state. During the war production rose from a prewar 10-year average (1931 to 1941) of 323,725 long tons (dried equivalent) to 6,020,684 long tons in 1943. The deposits, irregular in size and shape, are beds varying in thickness from a few inches to a maximum of 60 ft (average 12 to 15 ft). A few deposits outcrop, but most of them are discovered and developed by drilling. The maximum depth worked is over 300 ft. The beds are usually nearly horizontal: some have a dip of up to 15 deg and some are undulating. They are worked both by open-pit and by underground mining methods.

Other States. In recent years, outside of Arkansas, bauxite has been mined only in Alabama, Georgia, and Virginia, except for a minor tonnage from Kemper County, Miss., in 1942. In these southern states there are many known deposits, but most of them are small and irregular, although they have frequently been of high grade. Most of the small production has been for chemicals, refractories, and uses other than for aluminum. Recent production has come from the Eufaula district in Barbour and Henry counties, Ala., but deposits occur in Cherokee, De Kalb, Talladega, and Calhoun counties. In Georgia the Hatton and Thig Pen mines in the Andersonville district, Sumpter County, were still active in 1946, but mines formerly operated in Wilkinson, Floyd, Randolph, Meriwether, Macon, and Bartow counties are no longer in operation. During the Second World War the U.S. Bureau of Mines proved up large reserves of low-grade bauxite in the Andersonville district. In Virginia deposits worked near Spottswood, Augusta County, during the war were closed at the end of 1946.

In Oregon¹⁴ very large reserves of laterite or ferruginous bauxite were discovered in 1943 and proved by drilling from 1944 to 1949, first by the Oregon Department of Geology and Mineral Industries, then by the U.S. Bureau of Mines, and then in great detail by the Alcoa Mining Co. The deposits lie in Columbia, Multnomah, and Washington counties, northwest of Portland, just across the Columbia River from Vancouver, Wash., where Alcoa has an aluminum reduction plant. The nearly flat-lying deposits vary from 0 to over 20 ft thick under overburden 2 to 30 ft, averaging 13 ft. The average composition of the ore is roughly 31 per cent Al_2O_3 , 21 per cent Fe, 5 per cent TiO_2 , 11.5 per cent SiO_2 , and moisture about 20 per cent. By the Pedersen process² this ore could be made to yield both alumina and pig iron, possibly with a by-product of titanium.

Other Countries. Litchfield¹⁵ has shown that from 1904 to 1939, inclusive, the total world production of bauxite was about 43 million tons. About 98 per cent of this total had been produced by 10 countries as follows:

	<i>Tons (Approximate)</i>
France.....	13,000,000
United States.....	10,000,000
Hungary.....	4,000,000
Italy.....	3,400,000
Surinam.....	3,230,000
British Guiana.....	3,000,000
Yugoslavia.....	3,000,000
Russia.....	1,200,000
Dutch East Indies.....	820,000
Greece.....	680,000

The Second World War changed this production picture considerably. In 1946 the only large producing countries, in order of production, were British Guiana, the United States, Surinam, France, Russia, Gold Coast, and Hungary. The United States and Canada draw heavily on the deposits in Surinam and British Guiana, but United States interests are developing a deposit in Haiti, and deposits in the Dutch East Indies and Malaya may in the future supply some of our domestic plants.

Production and Consumption. Tables 1 to 4 from the U.S. Bureau of Mines give the most important statistics of the bauxite industry in recent years.

TABLE 1. SALIENT STATISTICS OF THE BAUXITE INDUSTRY IN THE UNITED STATES, 1945 TO 1948

	1945	1946	1947	1948
Production (crude ore)* long tons.	981,009	1,104,054	1,202,055	1,457,148
Value of production*.....	\$5,591,084	\$6,892,864	\$6,884,666	\$8,696,708
Imports,* long tons.....	739,581	852,005	1,884,666	2,488,915
Exports (including concentrates),† long tons.....	126,077	97,788	94,369	54,113
World production,† long tons.....	3,525,000	4,493,000	6,385,000	8,116,000

* Dried equivalent of mine production.

† As shipped.

TABLE 2. BAUXITE SHIPPED FROM MINES AND PROCESSING PLANTS IN THE UNITED STATES, 1944 TO 1948, BY STATES, LONG TONS

Year	Alabama, Georgia, and Virginia		Arkansas		Total	
	As shipped*	Dried bauxite equivalent	As shipped*	Dried bauxite equivalent	As shipped*	Dried bauxite equivalent
1944	132,533	129,568	2,788,019	2,568,770	2,920,552	2,698,338
1945	77,134	80,567	988,877	991,227	1,066,011	1,071,794
1946	52,505	53,829	1,049,125	964,945	1,101,630	1,018,774
1947	50,024	51,291	1,186,726	1,108,932	1,236,750	1,160,223
1948	59,520	59,474	1,430,688	1,314,069	1,490,208	1,373,543

* Includes crude, dried, calcined, activated, and sintered.

† Includes Mississippi.

Mining and Treatment. Most bauxite is mined on a large scale. In Arkansas¹⁶ by far the largest tonnage of ore mined has been from open-pit operations. Stripping is done by tractor-pulled scrapers, power shovels, and walking-type draglines. Hauling is by large-capacity trucks. After stripping, the top of the ore bed must be cleaned by small scrapers, pick and shovel, and heavy brooms. Mining is done by power shovel, with or without previous blasting. Underground mining is done by the room and pillar method. Mucking is done by hand

BAUXITE

or power loader. Hauling is accomplished by car or, in one case, by a system of belt conveyors.

Where possible, high-grade bauxites, that is, those low in silica and iron, are mined separately. Since high silica content is detrimental for most uses and since deposits high in silica must be used to an increasing extent, much of the bauxite mined today is treated in some way to reduce silica (usually as clay). This may be done in rake classifiers and screens or in log washers. During the Second World War the U.S. Bureau of Mines did extensive work on the beneficiation of low-grade bauxites and built a 50-ton pilot plant at Bauxite, Ark.¹⁸ Combinations of gravity concentration, classification, flotation, and magnetic separation were used, and partially satisfactory processes were developed.

TABLE 3. RECOVERY OF PROCESSED BAUXITE IN THE UNITED STATES, 1944 TO 1948, LONG TONS

Year	Crude ore treated	Processed bauxite recovered			
		Dried	Activated, calcined, or sintered	Total	Dried bauxite equivalent
1944	1,408,344	964,613	152,465	1,117,078	1,188,869
1945	874,180	522,533	132,525	655,058	719,416
1946	708,964	426,618	111,312	537,930	597,509
1947	655,702	410,727	102,320	513,047	564,829
1948	688,898	476,921	68,800	545,721	584,856

Since the points of use are at considerable distances from the mines in most cases and since bauxite, as mined, usually contains considerable free moisture, it is the usual practice at all large operations to dry or calcine the ore before shipment. This is done in rotary kilns. For the aluminum and chemical industries the ore is dried at about 1100°F and the mechanically held moisture is reduced to 0.5 to 1.0 per cent. For abrasives and refractories the ore is calcined at about 2000°F and the total moisture (mechanically and chemically combined) is reduced to about 0.5 per cent. The calcined product may be further treated by magnetic separation to remove iron.

Marketing and Shipping. Most of the largest users of bauxite operate their own mines, thus eliminating the problem of marketing. In the open market domestic bauxite is sold on a long-ton basis at a price fob cars shipping point, while French bauxite is quoted per metric ton cif Atlantic ports. Prices quoted depend upon chemical analysis. During the Second World War the Metals Reserve Co., the U.S. Government buying agency, set up a price schedule based on a long ton, dried basis, of ore containing 50 per cent Al_2O_3 and 13 per cent SiO_2 , with premiums for each unit of Al_2O_3 over 50 per cent and for each unit of SiO_2 under 13 per cent and penalties for each unit of Al_2O_3 under 50 per cent and for each unit of SiO_2 over 13 per cent. Later, a penalty was added for each unit of FeO over 6 per cent. Although this schedule was set up under war conditions it is indicative of what industries could use.

Prices. In early 1949, bauxite crushed and dried per long ton fob Arkansas and Alabama mines was quoted at from \$8.00 to \$8.50 for material running from 55 to 58 per cent Al_2O_3 , with Fe_2O_3 content from 1.5 to 2.5 per cent. Pulverized and dried, with 56 to 59 per cent Al_2O_3 and 8 to 12 per cent SiO_2 , it was quoted at from \$14 to \$16. Abrasive grade, crushed and calcined, 80 to 84 per cent Al_2O_3 , was listed at \$17 per ton.

TABLE 4. WORLD PRODUCTION OF BAUXITE, 1940 TO 1946, BY COUNTRIES, METRIC TONS
(Compiled by B. B. Mitchell)

Country	1940	1941	1942	1943	1944	1945	1946
Australia:							
New South Wales.....	2,081	2,671	1,832	734	2,025	1,700	a
Victoria.....	1,446	2,793	1,655	1,855	1,842	1,792	2,351
Austria.....		879	554	24	18,812	8,756	a
Brazil.....	82	14,365	29,890	76,761 ^b	2,979 ^b	7,060 ^b	1,161 ^b
British Guiana.....	634,510	1,060,979	1,215,744	1,919,060	928,178	678,482	1,137,991 ^b
France.....	489,020	587,420	639,560	916,350	665,630	252,416	478,242
French West Africa.....	3,390	a	a	a	a	a	a
Germany.....	8,911	12,478	13,752	a	a	a	a
Gold Coast.....		14,886	44,767	162,685	107,854	148,547	116,846
Greece.....	75,000	18,000	23,000	25,000	10,000	a	a
Haiti.....						300	300
Hungary.....	561,710	832,410	988,550	1,001,370	758,299	35,402	100,760
India.....	8,154	13,170	18,551	24,548	12,330	14,116	a
Indochina, French.....	118	10,200	12,800		360	a	a
Italy.....	571,324	536,881	509,430	210,634 ^c	a	2,584	65,447
Jamaica.....				2,642			a
Japan.....					2,000		
Netherlands East Indies.....	275,345	171,821	a	a	a	a	a
Palau Islands ^d	22,495	59,297	135,669	104,223	1,000		
Portuguese East Africa.....	1,030	1,352	1,860	3,372	6,177	4,369	a
Rumania.....	10,279	9,762	15,041	12,633	a	a	a
Spain.....		1,393	2,214	23,947	2,921	5,119	4,926
Surinam.....	615,434	1,198,900	1,227,512	1,655,147	625,804	683,990 ^b	570,639
Unfederated Malay States (Johore).....	63,787	a	a	a	a	a	a
U.S.S.R. (estimate).....	300,000	250,000	275,000	350,000	400,000	400,000	a
United Kingdom.....		13,090	95,724	107,924	44,502	36,981	a
United States (dried equivalent) ^e	446,253	952,082	2,643,775	6,332,868	2,869,021	996,754	1,090,044
Yugoslavia.....	245,195 ^f	203,000 ^f	86,000 ^f	a	a	a	a
Total.....	4,390,000	6,038,000	8,464,000	14,137,000	7,137,000	3,700,000	4,000,000

^a Data not available. Estimate included in total.

^b Exports.

^c January to June.

^d Imports into Japan and Formosa in fiscal year ended Mar. 31 of year following that stated; preliminary figures.

^e Mine production of crude ore.

^f Croatia only; estimate for rest of Yugoslavia included in total.

Crude, undried bauxite may be shipped in any type of cars, but dried or calcined ore is usually shipped in bulk in boxcars or in special closed-top, hopper-bottom cars.

Specifications and Tests. Bauxite is sold on the basis of alumina content, and deductions are made for high content of silica, iron, and titanium. Thus, the only way to determine the value of a bauxite is by chemical analysis, which should

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show total alumina, silica, iron oxide, titanium dioxide, and free and combined water. MacPherson¹⁶ gives the requirements shown in Table 5 for bauxite or the beneficiated products for various industries.

TABLE 5. GRADES OF BAUXITE OR PRODUCT

Industry	Form in which used	Percentage range in chemical content			
		Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	TiO ₂
Alumina-aluminum.....	Wet or dried	48-60	Up to 18	Up to 13	Up to 4
Abrasive.....	Calcined*	80-85	8	8.5	4.5
Refractory.....	Calcined	78-85	8	8.5	4.5
Chemical.....	Dried	52-60	13	2.5	3
Cement.....	Wet	52-56	3.5	15	4
Oil refining.....	Activated	75-80	10	9	4

* Calcined ores contain from 0.30-0.45 per cent combined water. Really high-grade bauxites contain 58-65 per cent Al₂O₃ and as low as 1 per cent iron oxide and 3-5 per cent SiO₂.

The quality of bauxite may often be determined in a general way by the simple test noted by Hill.

In general, bauxite of fair grade will not show the marks of a hammer when it is hit a glancing blow, though some bauxite has been shipped which can be cut with the hammer. Good bauxite, which has been dried either in the open or in kilns, when thrown on a hard floor has a distinct rattle which bauxitic clay does not have. The pisolites of the lighter colored bauxites of the central Georgia field have a peculiar brownish-buff color and look something like horn or flint; they ordinarily cannot be broken or marked with the finger nail in bauxites of good grade.

Some measure of the relative quality of dried bauxite can be had by grinding a sample in an agate mortar for half a minute. A bauxite of good grade will be found hard to grind and will stick to the mortar with such tenacity that it will have to be scoured out; a poor bauxite or bauxite clay will grind much more easily and will stick very little, if at all; and clay or kaolin grinds with ease and does not stick to the mortar. Similar results are found if the sample is rubbed on glass and the glass will not be scratched by even high-grade bauxite.⁸

Utilization. In 1946 about 80 per cent of the bauxite consumed in the United States was made into alumina, mostly for metallic aluminum. However, part of this alumina went into the chemical abrasive and refractory industries and part into special alumina products such as activated alumina. Table 6 shows the distribution of consumption by major uses. If the "Alumina" classification in this table were broken down into end uses and those uses other than for aluminum were redistributed into their proper end uses, the tonnages in the other three classifications would, of course, be larger (see also the "Alumina" classification at the end of Table 7).

Aluminum Salts. Aluminum salts are made chiefly from bauxite. In 1946 the tonnage so used was 262,275 long tons. In addition to bauxite other raw-material sources of alumina used for chemicals included 73,883 tons of clay, 19,882 short tons of aluminum trihydrate, 11,977 tons of secondary aluminum and a

TABLE 6. BAUXITE CONSUMED IN THE UNITED STATES, 1947 TO 1948, BY CONSUMING INDUSTRIES, LONG TONS (Dried-bauxite equivalent)

Industry	1947			1948		
	Domestic	Foreign	Total	Domestic	Foreign	Total
Alumina*.....	869,796	1,258,135	2,127,931	965,081	1,314,042	2,279,123
Chemical.....	104,038	41,094	145,132	115,264	42,613	157,877
Abrasive and refractory.....	204,781	54,478	259,259	125,030	122,277	247,307
Other.....	22,576	9,544	32,120	26,334	14,499	40,833
Total.....	1,201,191	1,363,251	2,564,442	1,231,709	1,493,431	2,725,140

* Includes some bauxite used in making chemicals and other products.

TABLE 7. ALUMINUM SALTS AND ALUMINA PRODUCED AND SHIPPED IN THE UNITED STATES, 1947 TO 1948

	1947				1948			
	Production	Shipments			Production	Shipments		
	Short tons	Shippers	Short tons	Value	Short tons	Shippers	Short tons	Value
Aluminum salts:								
Alum:								
Ammonia.....	5,007	5	5,299	\$393,839	5,768	4	5,931	\$417,992
Potash.....	3,782	4	3,633	304,098	2,744	3	3,334	250,436
Aluminum chloride:								
Liquid.....	6,862	4	6,643	263,384	9,553	5	9,439	425,234
Crystal.....	18,268	2	18,079	3,045,440	17,403	1	17,528	2,923,057
Anhydrous....		6				5		
Aluminum sulfate:								
Commercial:								
General.....	595,612	17	582,222	13,469,279	648,480	14	646,022	15,521,015
Municipal....	10,755	8	10,671	162,595	14,829	8	14,891	318,055
Iron free.....	24,371	8	24,419	985,489	25,193	6	24,404	1,081,452
Sodium aluminum sulfate.....	25,538	2	24,103	1,829,971	26,154	2	25,972	2,210,050
Sodium aluminate		8				10		
Total aluminum salts.....	690,195	37	675,069	\$20,454,095	750,124	37	747,521	\$23,147,291
Alumina*.....	78,238	7	79,292	6,774,282	82,512	7	60,080	5,605,013

* Excludes alumina produced for use in making aluminum; includes activated, calcined, crude, light and heavy hydrate, converted to a calcined alumina equivalent.

quantity of alunite and bichromate residues. Table 7 shows the production of aluminum salts and alumina in 1947 and 1948.

In 1946, 28 per cent of the "Alumina" shown in Table 7 was used for making aluminum salts and the balance for abrasives, refractories, petroleum refining, spark plugs, glass, rubber, paints, and other end products.

Aluminum sulfate of commercial grade, for water purification, is made by digesting bauxite with sulfuric acid. For this use bauxite should be high in acid-soluble alumina and low in acid-soluble iron oxide. The percentage of chemically combined water in bauxite is a general guide to the acid solubility of the alumina. Trihydrate bauxites (with about 30 per cent loss on ignition) are much more acid soluble in the common acids than the monohydrates.

Iron-free alumina or "concentrated alum" is made by the Bayer process by calcining, at a white heat, a mixture of ground bauxite and soda ash. The resulting mass is ground, lixiviated rapidly with water, filtered, and treated with carbon dioxide. The precipitated aluminum hydrate is then added to hot concentrated sulfuric acid until frothing ceases. It is used largely in paper making for sizing; as a mordant in dyeing; for water purification; in tanning; for deodorizing and decolorizing mineral oils; and for other uses where crude alum was formerly used.

The term "alum"* is a general name given to the double sulfates of aluminum and the alkali metals, with iron and chromium sometimes replacing the aluminum. The most important commercial types are the ammonia, potash, and soda alums. Ammonia alum has largely replaced potash alum, due to its cheapness. Soda alum, while cheap, does not crystallize well and is not so extensively used. Alums are usually made in this country by mixing in exact quantities aluminum sulfate and the necessary alkali sulfate. Alum is also made, principally in Europe, from natural alum rock, alum shales, alum schists, etc. The chief uses for alum are the same as those given above for aluminum sulfate.

Aluminum hydroxide, made largely by the Bayer process, is used principally in the manufacture of other aluminum compounds; also in the preparation of lake colors, in waterproofing fabrics, and in medicine.

Aluminum chloride is made commercially in this country by briquetting a mixture of calcined bauxite and carbonaceous residues, calcining to drive off hydrocarbons, and chlorinating at about 1600°C in a shaft kiln. The volatilized aluminum chloride is then condensed. It may also be made by reacting liquid or gaseous chlorine with metallic aluminum and by the action of hydrochloric acid on aluminum carbide at temperatures of 600 to 900°C. It is used in the refining of mineral oils, for the carbonizing of wool, and in the manufacture of certain organic compounds.

Aluminum fluoride, made by reacting aluminum hydrate with hydrofluoric acid, is used, along with cryolite, as a bath component in the Hall process for making aluminum.

Sodium aluminate, used for boiler water treatment and, with aluminum sulfate, in municipal filtration plants, is made by fusing bauxite with soda ash or by digesting it with caustic soda.

* See Alum.

Aluminum acetate, known as "red liquor," may be prepared either by (1) the action of acetic acid on aluminum hydrate, or (2) the interaction of aluminum sulfate and calcium or lead acetate. It is used as a mordant in calico printing and dyeing, for the formation of lake colors, and in waterproofing and fireproofing fabrics.

Bauxite Abrasives. Bauxite abrasives are made by fusing bauxite with carbon in an electric furnace, breaking down the fused product, pulverizing, and sizing the grains. If made from pure bauxite, the product is really practically an artificial corundum. By varying the grade of bauxite used, the hardness and the toughness of the abrasive may be varied.

It is also used for the manufacture of acid- and heat-resisting chemical apparatus, such as porous filtering media and crucibles.

High-alumina Refractories. High-alumina refractories are arbitrarily distinguished from other refractories containing alumina by having an alumina content of at least 58 per cent. Such refractories are ordinarily made from bauxite or bauxite and high-alumina clays, such as bauxitic clays and diaspore clays. Ordinary bauxite brick are made by mixing calcined bauxite or high-alumina clay with a bonding material, such as fire clay, sodium silicate, or lime; shaping by hand or by brick machines; and burning in various types of brick kilns at a high temperature. Another class of bauxite refractories is made by fusing bauxite in an electric furnace and casting the molten material in molds. Pure bauxite melts at about 1820°C , and pure alumina at about 2050°C ., but the lower grades of bauxite brick melt at 1740°C or less. The value of bauxite refractories depends upon their chemical inertness at high temperatures. In basic open-hearth steel practice, bauxite brick should contain over 12 per cent silica.

High-alumina refractories are made more commonly today from diaspore and high-alumina clays than from bauxite.

High-alumina Cements. High-alumina cements, which are essentially calcium aluminates with very low silica, are becoming of great importance. They have been made by fusing, in a small blast furnace, a mixture of bauxite, coke, and limestone. The slag, when poured, cooled, and ground, forms the finished cement. This cement contains 40 to 50 per cent lime, 40 per cent alumina, 10 per cent silica, and 10 per cent iron oxide, and is known as fused cement, Lafarge cement, "ciment fondu," and "ciment électrique" (in Europe).

The principal advantage of such cements over ordinary portland cement is that they harden much faster and develop nearly their full strength in a very short time. It is stated that such cements will show a strength at the end of 24 hr rarely shown by portland cements in less than 28 days. During the First World War, fused cement was manufactured in France in large quantities for making heavy-gun emplacements and other structures where great strength was needed in a very short time. Fused cement has the additional advantage of being highly resistant to sea water and similar solutions.

High early strength has been developed in ordinary portland cements by fine grinding and increasing the lime content. These cements are much cheaper than calcium aluminate cements and satisfy much of the demand for this type of

product, but they cannot compete where resistance to chemical attack and high temperatures is important.

Activated Bauxite. By calcining bauxite at a temperature such that part but not all of the combined water is driven off it has adsorbent properties similar to those of fuller's earth and activated clays. This product has found considerable use in the petroleum industry, particularly for bleaching lubricating oils, a use that began in this country about 1937. Activated bauxite has an advantage over fuller's earth in that it may be revived and reused indefinitely, while fuller's earth gradually deteriorates. Activated bauxite is also used as a drying adsorbent, as a catalyst, and as a catalyst carrier. For this use bauxite should be high in alumina and dense and hard, so that nondusting granules may be made.

Other Uses. Activated aluminas are used as desiccants, catalysts, and catalyst carriers. Calcined aluminas are used in ceramics, glass, porcelains, high-grade refractories, and electrical insulators. Hydrated aluminas are used in ceramics, glass, and water softeners. Very fine particle size (0.5μ) grades are used as fillers in rubber, plastics, cosmetics, and paints.

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BENTONITE

Definition. The term "bentonite" is not an exact mineralogical name nor is the material of a definite mineralogical composition with definite physical and chemical properties. Originally the term was applied only to a greenish-yellow, exceedingly plastic, claylike material found in the Laramie and Big Horn basins of eastern Wyoming and western South Dakota. An outstanding characteristic of this material was its ability to swell enormously when wetted with water. Later, other claylike materials having some of but not all the characteristics of the original bentonite began to be called by that name, although most of them were nonswelling. Petrographers classed as bentonites all clays derived from volcanic ash that consisted chiefly of the minerals montmorillonite or beidellite or of mixtures of the two. On this basis bentonites may be divided into two classes based on physical properties: (1) those which swell greatly and absorb large amounts of water, and (2) those which swell, when wetted, no more than ordinary plastic clays.

Based on the property of adsorption or surface activity bentonite grades into fuller's earth. The nomenclature is so loose that producers of adsorptive clays have sometimes reported their production to the Bureau of Mines as bentonite and sometimes as fuller's earth, thus greatly confusing the statistical picture.

Perhaps the best classification of bentonites and similar clays, based on adsorptive characteristics, is that given by Nutting⁹ and quoted below.

I. *Inactive and nearly inactivable montmorillonite clay of the bentonite type.* Some of these, occurring abundantly in the region north and west of the Black Hills, swell greatly and gel freely in water and are valued for drilling muds, for waterproofing earthen dams and reservoirs, as carriers of insecticides, and as additions to molding sands.

II. *Inactive but highly activable clays,* chiefly very pure bentonite such as occurs in the Vicksburg group of Oligocene age in central Mississippi and in the Oligocene of northeastern Arizona. The highest grade activated clay is prepared from clays of this class.

III. *Active and highly activable clays.* These occur in extensive deposits in north-west Florida; Brooks County, Ga.; Jasper County, Tex.; and Morden, Manitoba. English fuller's earth is in this class. It and the Texas clays have been extensively used as naturally active clays, but none have yet been activated commercially.

IV. *Active clays little affected by acid treatment.* The well-known Porters Creek clay, which is mined at Olmstead, Ill., and extends in a thick belt southward to Alabama, is typical of this class. Its thermal dehydration curve suggests that it may be an altered and reworked bentonite mixed with silt.

V. *Active clays whose activity is lowered by acid leaching.* The well-known fuller's earth of northern and central Florida is a typical example. Its origin is uncertain, but material having similar properties may be produced from bentonite by long treatment with dilute acid, and many deposits grade off into activable clay of type II at the bottom or to one side.

Material belonging to classes III, IV, and V is called fuller's earth; it may be used after no other treatment than drying and grinding. These clays commonly dry into hard masses, are readily granulated, and do not disintegrate in water. The swelling property of some class I bentonites is probably due to saturation with sodium, because other clays and soils may be given the same property by soaking in soda solution. The Ordovician bentonite, high in insoluble potash, belongs to class III. The composition of the clay from Marianna, Fla. of class III corresponds closely to beidellite, but by no means do all clays of that class have that composition.

The characteristic properties of clays of classes I, IV, and V are very persistent, but those of classes II and III change rapidly on room drying. The swelling bentonite is extremely resistant to weathering, stream washings, and redepositions, retaining its original swelling property and never altering to another class.

In addition to Nutting's five classes there are fine-grained plastic clays used for oil-well drilling muds and for foundry use which are not of volcanic origin but which are sometimes called bentonites by their producers. Some of the California clays are in this group and were once, but no longer, classed as bentonites by the U.S. Bureau of Mines.

Composition. The one mineral essential to the composition of true bentonite is montmorillonite, which has been assigned the theoretical formula $\text{Al}_4\text{Si}_8\text{O}_{20} \cdot (\text{OH})_4 \cdot x\text{H}_2\text{O}$, in which Mg usually replaces part of the Al and often part of the Si. The formula for montmorillonite is also sometimes given as $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, and also as $(\text{Mg}, \text{Ca})\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 \cdot n\text{H}_2\text{O}$ with n equal to about 8. Beidellite, another mineral of the montmorillonite group usually found in true bentonites, has a formula much like that of montmorillonite except that it has 3SiO_2 instead of 4 and forms an isomorphous series with nontronite, which is similar to beidellite except that the Al_2O_3 is replaced by Fe_2O_3 . In the swelling type of bentonites sodium is usually present. Calcium and magnesium are common constituents of montmorillonite. Hectorite is a lithium-bearing magnesium bentonite found at Hector, Calif. Sauconite is a zinc-magnesium-aluminum-iron bentonite.

Analyses of typical bentonites are given in Table 1.

Physical and Chemical Properties. Since bentonites include materials of such wide and variable chemical composition it is natural that they vary greatly in physical and chemical properties. The type of material from the Black Hills area of Wyoming and South Dakota is light yellow or greenish yellow in color, but from other localities it may be cream-colored, white, gray, pink, dark brown, or even

black. It is exceedingly fine grained, very plastic, and highly adsorbent. The appearance may be dull or powdery, but a freshly cut surface usually has a waxy luster. Some varieties have the appearance of wax and may be cut into very thin, translucent shavings. The fracture of the type material is roughly conchoidal; other types are platey and shale-like, while still others have no typical fracture. Some bentonites are highly absorbent, absorbing up to 5 times their

TABLE 1. ANALYSIS OF BENTONITE

	1	2	3	4	5	6	7	8
SiO ₂	60.64	57.98	58.68	59.84	60.18	63.20	54.00	55.22
Al ₂ O ₃	23.26	22.46	25.91	11.84	26.58	12.90	24.48	21.00
Fe ₂ O ₃	3.92	3.80	3.97	3.26	.....	2.46	3.00	3.61
TiO ₂	0.12	.....	0	.....	.....	0.11	.....	.....
CaO.....	0.59	1.92	1.45	2.90	0.23	0.82	2.08	4.94
MgO.....	2.19	3.24	1.49	2.32	1.01	2.09	2.75	3.04
K ₂ O.....	0.37	1.35	{ 0 1.39	{ 2.34 2.13	1.23	{ 0.26 0.66	1.74	1.56
Na ₂ O.....	4.33							
SO ₃.....	.....	0.75	0.11	.....	.....	.....	.....	0.43
CO ₂.....	.....	.....	Trace	.....	.....	3.50*	.....	Trace
Cl.....	.....	.....	0.10	.....	.....	0.20†	.....	0
P ₂ O ₅.....	.....	.....	0.06	.....	.....	.....	0.71	.....
Ignition loss.....	.....	7.93	.....	10.50	.....	.....	.....	.....
H ₂ O.....	2.83	.....	6.84	.....	10.26	13.80	9.12	10.28
Total.....	98.25	99.43	100.00	95.13	99.49	100.00	97.88	100.08

* Sand, etc.

† Water-soluble.

1. Yellow, colloidal; Bell Fourche, S. Dak.; Analyst, W. A. Selvig, U.S. Bur. Mines.

2. Yellow, colloidal; Medicine Bow, Wyo.; Analyst, A. G. Van Eman, Owyhee Chemical Products Co., Chicago, Ill.

3. White, colloidal; near Barstow, Calif.; analysis from California Master Products Co., Los Angeles, Calif.

4. White, fine-grained; Otay, San Diego County, Calif.; analysis from Otaylite Products Co., Los Angeles, Calif.

5. Type material from near Rock Creek, Laramie Basin, Wyo.; Analyst, T. T. Read, Cassa Mining Co.

6. From Big Horn Basin, Wyo.; Analyst, R. C. Wells, U.S. Geol. Survey.

7. Supposed bentonite, near Shelbyville, Tenn.; analyst unknown.

8. "Ardmorite," probably variety of bentonite; Ardmore, S. Dak.; analysis from the Refinite Co., Omaha, Nebr.

weight or 15 times their volume of water, with a consequent increase in volume and the formation of a slippery, plastic, gelatinous mass that resembles soft soap. Upon thorough drying the gelatinous mass will shrink back to a hard, dense, hornlike substance. The best grades of swelling bentonite will expand 12 to 15 times their original volume—in extreme cases up to 30 times. Such bentonites may form very permanent emulsions or suspensions in water. Other varieties may be readily dispersed in water, but the suspensions are not permanent.

Some nonswelling bentonites, when acid treated, acquire the ability to adsorb and remove coloring material from oils, fats, and greases and are thus competitive with fuller's earth. Base-exchange properties are well developed in some varie-

ties; that is, when in suspension in water they have the property of easy replacement of the alkaline and earth oxides, one with another. This property has been utilized for the softening of hard water. If hard water containing calcium sulfate be passed through a bed of base-exchange bentonite granules containing sodium, the calcium sulfate is changed to sodium sulfate (soluble) and the sodium in the bentonite is replaced by calcium. The process is reversible and the bentonite may be rejuvenated by passing through it a solution of sodium chloride.

Occurrence. Most bentonites are now regarded as being alteration products of volcanic ash, the alteration having taken place during or shortly after the deposition in water of wind-blown ash. A few deposits seem to have been formed by the alteration of glassy lava flows and still fewer from acid igneous rocks such as rhyolite. They nearly always occur in well-defined beds from a few inches up to 10 or 12 ft thick, but occasionally in irregular pockets.

Geographically, bentonites in general have a wide distribution, deposits being reported in over half the states of the Union, with production in recent years coming from 9 or 10 states. As noted before, however, some material formerly called bentonite is now regarded as fuller's earth or as miscellaneous plastic clay. Swelling-type bentonites are very much scarcer and commercial production comes almost wholly from the type localities in Wyoming and South Dakota.

While commercial production, disregarding the minor exceptions of Canada and Italy, has been practically confined to this country, deposits have been reported in Russia, Poland, Germany, Rumania, France, South Africa, China, Japan, New Zealand, and Mexico.

United States. Wyoming-South Dakota Area. This area, in 1945 and 1946 furnishing about two-thirds of the total domestic production, covers two main districts, with numerous other small deposits fairly remote from them. The largest district and the type area for swelling-type bentonite is the Black Hills area of northeastern Wyoming and the adjacent portions of western South Dakota, centering about Newcastle, Wyo., and Belle Fourche and Sturgis, S. Dak. In general, the beds of bentonite, varying in thickness from a few inches up to 3 or 4 ft, dip at a gentle angle (5 deg in one case) under a few feet of loose overburden, which is removed by scraper. The clay is dug with power shovels and transported to the mills, where it is dried and pulverized either in hammer mills or in roller mills with air separation and packed in paper bags. Some of the product is also shipped as crude, either to customers or to grinding mills near centers of consumption, *e.g.*, Chicago. A second district in Wyoming is in the Big Horn Basin centering about Greybull. Heathman⁸ in 1939 reported eight series of deposits in Wyoming with 22 recorded outcrops. A variety of bentonite, not of the swelling type, occurring at Ardmore, S. Dak., locally called "ardmorite," has base-exchange properties and was once produced for water-softener use.

California. "In California, the largest known bentonite deposits occur in the arid desert regions along the Amargosa River in Inyo County. The material in these deposits is known as 'shoshonite' and 'amargosite' and its analysis corresponds to that of montmorillonite. At Otay, near San Diego, a large lenticular deposit of bentonite, locally known as 'otaylite,' has been worked on a consider-

able scale for use in oil refining. Near Barstow, in San Bernardino County, a light cream-colored bentonite is mined. At Ventura, the bentonite forms a soft soapy clay with a slight greenish cast. Operations have been carried on in other counties."²

*Mississippi.** Bentonites, chiefly used with or without chemical activation for oil bleaching, have been produced in several areas in this state. Among the more important localities are near Polkville and Lemon, Smith County, near Smithville, Monroe County, and near Aberdeen, Amory, and Pontotoc. The Filtrol Co. treats Polkville bentonite at a plant at Jackson.

Texas.^{8,10} The chief bentonite deposits in Texas lie in a band 4 to 20 miles wide in a curved line roughly 100 miles inland and parallel to the Gulf Coast. The most productive areas are in Karnes, Gonzales, Fayette, Jasper, and Tyler counties. Important commercial operations are near Gonzales, Brownell, and Falls City. Production is principally for bleaching clay, but the white firing types may be of interest for porcelain bodies, glazes, and enamels.

Arizona. An important deposit of high-grade, activable bentonite, 2 to 6 ft thick, extends for 30 miles or more along the Puerco Valley from Navajo to Allentown. Chito and Chambers have been important producing centers.

Other States. Other minor producing states in recent years have been Montana, Utah, Colorado, Nevada, and Oklahoma, but deposits are reported in many other states.[†] It should also be noted that many deposits formerly called bentonites are now classed as fuller's earths.

Canada.¹⁴ Bentonite deposits have been reported at numerous localities in western Canada and a few have been worked in a small way, but important production has not yet resulted. Some of the better known deposits are near Morden and Thornhill in southern Manitoba; near Edson and near Milk River in Alberta; near Princeton, British Columbia; and near Knollys, Saskatchewan.

Italy. Just before the Second World War deposits of white bentonite, reported to be among the largest known outside the United States, were opened in Italy, and small shipments were made to this country. They occur on the Island of Ponza in the Pontine Islands. This bentonite is very low in iron and fires white up to 1000°C. It was suggested that its most important uses might be in the ceramic industries.

Other Countries. *Russia, Rumania, Argentina, and Japan* are reported to be well supplied with both swelling and nonswelling types of bentonite. Occurrences of bentonite are reported in Germany, Poland, France, South Africa, China, New Zealand, and Mexico.

The well known fuller's earths of England are reported by Nutting⁹ to be true bentonites but they have traditionally been called fuller's earths and that term will probably persist.

Production. In 1946 the Wyoming-South Dakota area accounted for 66 per cent of the total United States production, of which 35 per cent was from Wyoming and 31 per cent from South Dakota. Texas produced 4 per cent and the bulk

* See P. G. Nutting: Adsorbent Clays, Their Distribution, Properties, Production, and Uses, *U.S. Geol. Survey, Bull.* 928-C, 1943, pp. 146-147.

[†] *Op. cit.*, pp. 141-157.

BENTONITE

of the remainder came from Mississippi and Arizona, with minor tonnages from Montana, California, Utah, Colorado, Nevada, and Oklahoma.

TABLE 2. BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1946 TO 1948, BY STATES

State	1946		1947		1948	
	Short tons	Value	Short tons	Value	Short tons	Value
California.....	*	*	5,328	\$ 55,500	18,676	\$ 101,450
South Dakota.....	186,707	\$1,394,378	186,450	2,070,659	156,701	1,702,430
Texas.....	21,576	192,891	18,628	146,187	29,926	282,636
Wyoming.....	212,530	1,988,918	259,084	2,583,255	383,815	3,682,734
Undistributed†.....	180,615	785,227	294,399	1,093,985	332,442	1,367,658
	601,428	\$4,361,414	763,889	\$5,949,586	921,560	\$7,136,308

* Included with "Undistributed."

† Includes Arizona, Mississippi, and Utah; in addition, Colorado and Montana in 1945 to 1946 and California, Nevada, and Oklahoma in 1946.

Mining and Treatment. Most bentonite deposits occur close enough to the surface so that they may be extracted by open-pit methods with power shovel or scraper. In a few cases underground mining operations are necessary.

As mined, bentonite commonly carries considerable moisture, even to the extent of being sticky. In California it is common practice to air-dry the freshly mined clay, either on the open quarry floor or on drying platforms, to reduce the moisture from about 30 per cent down to about 7 per cent. The drying may also be done mechanically in rotary driers. Care must be taken not to reduce the water content lower than the safe minimum that must be established by experiment for each clay.

For many uses the dried clay is pulverized in roller or swing hammer mills and bagged for shipment. If the clay is to be used for bleaching purposes and must be activated, further treatment is necessary. An acid treatment is usually employed, using either sulfuric or hydrochloric acid, the former being most common in this country due to lower cost. The dried and finely pulverized clay is mixed with nearly concentrated acid, in either batch or continuous mixers. The mixture is kept at slightly over 212°F and vigorously agitated. The time of contact with the acid depends upon the nature of the clay and the strength of the acid, ranging from 2 to 12 hr. After acid treatment the clay is drained or filtered, washed with clean water, filtered, dried, pulverized, and bagged for shipment. The uncombined moisture content of the finished clay is usually held at about 15 per cent. To obtain a uniform, high-quality product close technical control of the process is necessary.

Prices. In early 1950 carload lots of bulk material, crushed and dried, were priced at \$8 per ton fob Wyoming. Pulverized, 200 mesh, in paper bags, was quoted at \$11 per ton fob Wyoming.

Specifications and Tests. Chemical analyses are of little value for determining the suitability of a bentonite for most commercial uses. Most uses depend upon the physical properties of bentonite and, since both methods of use and types of bentonite are so diverse, specialized tests for each intended or suggested use must be made. Thus, a bentonite of high value for bleaching oil may be of poor quality for bonding molding sands. Nutting⁹ covers in considerable detail the properties and methods of testing of adsorbent or bleaching clays. Stern^{15,16} gives in detail the testing methods used for clays for oil-well-drilling muds. Grim and Cuthbert⁵ discuss the properties of clays used for bonding molding sands. Davis, Vacher, and Conley² cover general methods of testing and identifying bentonites. The subject is so detailed and complicated that it cannot be covered briefly.

Utilization. Bentonite is one of our most interesting and versatile minerals, and scores, if not hundreds, of uses have been tried or suggested. Davis, Vacher, and Conley² devote 25 pages to uses and another 6 pages to United States patent listings up to about 1939. However, most of the suggested uses have not developed into large tonnage markets. In 1946 three main uses accounted for nearly 90 per cent of the production, leaving only about 10 per cent for all the other minor uses. Since 1942 the fastest growing use was in oil-well-drilling mud, the percentage of total production rising from about 13 per cent in 1942 to about 38 per cent in 1946. Changes in the utilization pattern in the United States from 1934 to 1946 are shown in the chart (Fig. 3) from the Bureau of Mines.

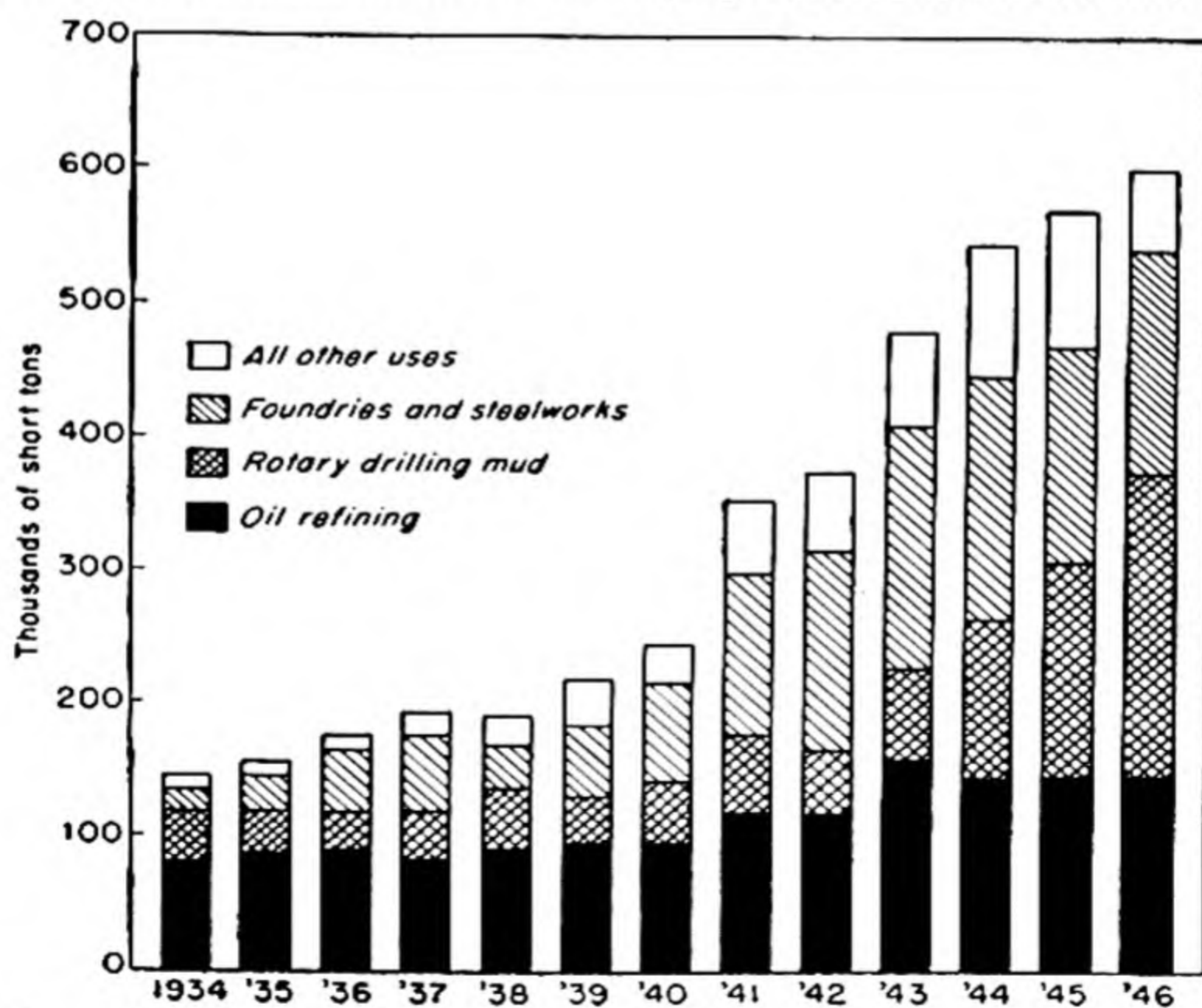


FIG. 3. Bentonite sold or used by domestic producers, 1934 to 1946.

In oil-well drilling¹⁴ bentonite and other colloidal clays are used in drilling fluids, known as "mud," for several purposes. The viscous suspension serves to plaster the sides of drill holes to prevent cave-ins, to reduce loss of drilling fluid by seepage, to carry sand and drill cuttings up out of the hole, and to hold cuttings in suspension and prevent them from packing in the bottom of the hole when the drill is stopped. They also hold in suspension heavy minerals such as barite used to make high-density drilling muds. Both the swelling and the nonswelling types of bentonite (as well as other clays) are used for this purpose, but the non-swelling types are generally favored.

The second largest present use is as a bond in molding sands.⁵ For this use the swelling type is most widely used, but other types of plastic, nonbentonitic clays are also used for this purpose.

Formerly the largest single use for bentonite (perhaps due to inclusion in production statistics of clays now not classified as bentonite) but now the smallest of the three major uses is as an adsorbent clay for bleaching oils. For this use it competes with fuller's earth, activated bauxite, and many other artificial adsorbents.

Among the many smaller applications are its use as a filler, binder, and plasticizer in paper, paint, rubber, linoleum, oilcloth, etc.; as a suspending agent in horticultural sprays and cold-water paints; as a colloidal base for pharmaceutical and cosmetic preparations; in water and sewage treatment, for softening hard water, for adsorbing impurities, and for assisting in coagulation of bacterial contaminants; in the preparation of a mica substitute known as "Alsifilm"⁸; in cements and mortars to increase plasticity and workability, decrease segregation, and decrease permeability of concrete and other porous formations; in cleaning and polishing compounds; in soaps and detergents; as a base for lake colors; in paper coatings; and in ceramics, both as a suspension agent in slips and slurries and as an ingredient of porcelains, enamels, and glazes.

Bentones are chemical derivatives of bentonite made by reaction with organic ammonium salts. They impart viscosity and thixotropy to products. Bentone 8, for example, is an alkyl ammonium derivative for paints, lacquers, etc., to produce flat or semigloss finishes.*

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BERYLLIUM MINERALS

The beryllium group of minerals is an example of growth in importance through research. Their properties have been determined, means have been devised for the extraction of metallic beryllium, and a large number of applications in industry have been found. Known resources are few in number, limited in extent, scattered over wide areas, and not productive at low cost. Potential demand is in excess of the presently known supply. Beryllium is not an excessively rare element and is found in a large number of minerals, but practically all are of rare occurrence and are not known to exist in tonnages of commercial significance. The composition of the most common beryllium minerals is shown in Table 1.

* Contains good bibliography.

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TABLE 1. PERCENTAGE COMPOSITION OF BERYLLIUM-CONTAINING MINERALS

Mineral	Formula	BeO	Al ₂ O ₃	SiO ₂	MnO ₂
Beryl.....	3BeO·Al ₂ O ₃ ·6SiO ₂	14.0	19.0	67.0	
Chrysoberyl.....	BeO·Al ₂ O ₃	19.8	80.2		
Phenacite.....	2BeO·SiO ₂	45.55	....	54.45	
Helvite.....	Mn ₄ Be ₃ Si ₃ O ₁₂ S	13.6	....	32.5	51.0
Vesuvianite.....	Not definite	9.2	9.7	34.25	

Beryl containing 14 per cent BeO is rare. Most material contains about 12 per cent BeO or less. Accurate analysis invariably discloses the presence of some cesium. In addition to the minerals listed above a considerable number of others are known. Among them are bertrandite, gadolinite, beryllonite, hambergite, euclase, alvite, and others. Most beryllium minerals are found in pegmatites, granites, or in contact masses near intrusions that have caused marked metamorphism. Apparently, beryllium accumulates in the last fraction of a magma to crystallize, following the common rule that the lightest elements are the best mineralizers, and remain in the most fluid part of the magma or the agents forming hydrothermal veins. Beryl is by far the best known beryllium mineral and the only one to be produced in commercial tonnages.

BERYL

Beryl is generally found in simple, prismatic, hexagonal prisms, from microscopic in size to over a foot in diameter by several feet long. The best known varieties are *emerald*, colored bright green by small amounts of chromium; *aquamarine*, blue to sea green in color; *yellow* or *golden beryl*; *morganite* or *cesium beryl*, pale to rose-pink color due to small amounts of cesium; and *common beryl*, generally opaque and often in extremely large crystals.

Physical Properties. *Hardness*, 7.5 to 8. *Specific gravity*, 2.6 to 2.8. *Index of refraction*, 1.575 to 1.598. *Color*, various shades of green, blue, yellow, reddish, white, or colorless, sometimes mottled. *Streak*, white. *Luster*, vitreous. *Cleavage*, imperfect basal and prismatic; conchoidal to uneven fracture. *Transparency*, transparent to nearly opaque. *Tenacity*, brittle.

Gem varieties of beryl, such as aquamarine, are usually found as clear, unflawed areas in larger crystals or masses of opaque material rather than as single clear crystals of gem quality, but sometimes such clear crystals are found.

Occurrence. Beryl is commonly found in pegmatites, the coarsely crystallized equivalent of a granite. Pegmatites are of fairly rare occurrence and are exposed only in areas of deep erosion; therefore, they are by no means a common rock structure. Beryl has been found in Maine, New Hampshire, Massachusetts, Connecticut, New York, Colorado, New Mexico, and South Dakota in quantities of commercial significance. It has been found also in Virginia, North Carolina, California, Pennsylvania, Wyoming, and other states. The presence of pegmatites does not ensure the presence of beryl. It is notably deficient in western North Carolina in the area of the most active feldspar and mica mining in pegmatites in the United States. Production is centered in the lithium-rich pegmatites

of the Keystone district in South Dakota. Crystals of remarkable size have been found there; the largest, discovered in 1944, weighed 61.25 tons. Large crystals weighing tons have been found also in Maine. Beryl is found in quantity in India, Madagascar, Australia, Argentina, and Brazil. Beryl is not restricted geologically to pegmatites; it is found as well in schists, gneisses, slates, and limestones. These deposits probably have been formed by the introduction of beryllium solutions from nearby igneous intrusions.

Production. Production in the United States is entirely as a by-product of the mining of mica, feldspar, and lithium ores. As shown in Table 2, production is restricted largely to South Dakota. The mines, actually quarries, in coarsely crystalline pegmatites are drilled with jackhammers, and the rock broken with explosives. Blasting powder has been used at times in place of dynamite in order to produce a minimum of fines. The broken rock is sorted by hand and such beryl as is encountered is placed aside and stock-piled until enough has accumulated to form a shipment. Because of the irregular distribution of the beryl in large crystals several tons may be extracted in a few days and little more found for months. Determination of the amount of beryl in an ore body or prediction as to the reserves for future use with satisfactory accuracy is impossible. Production in the United States is given in Table 2 and world production in Table 3. Practically all beryl originates in Brazil, Argentina, India, and Australia.

TABLE 2. BERYLLIUM ORE SHIPPED FROM MINES IN THE UNITED STATES, SHORT TONS

State	1943	1944	1945	1946	1947	1948
Colorado.....	68	35			a	a
Maine.....	2	2			a	a
Massachusetts.....		4				
New Hampshire.....	42	.....	1	5	a	a
New Mexico.....		29			a	
South Dakota.....	238	306	38	95	70	45
Others.....	6	12			75	54
Total.....	356	388	39	100	145	99
Value.....	\$44,407	\$56,135	\$6,133	\$17,787	\$25,214	\$26,600

^a Data not available.

Utilization. The rare, small, emerald-green crystals have been prized as gems for centuries. The finest quality material sells at prices comparable to those of the diamond. These emeralds have been found at Muzo and Chivor in Colombia; in the Ural Mountains, Russia; in Upper Egypt; in Tyrol; and in small quantity in North Carolina. Blue beryl is used as the popular gem, aquamarine, and the rarer pink variety is sold as morganite. Ground common beryl has been substituted in part for feldspar in the manufacture of ceramic bodies.¹⁷ The porcelain produced showed improved resistance to impact and a superior dielectric strength. It is probable that such usage would be substantial today if the raw material were available at a competitive price. BeO has great potential use as a

BERYLLIUM MINERALS

refractory and an abrasive. Metallic beryllium displays remarkable properties of lightness in weight and strength. Its specific gravity is 1.93, compared to aluminum with a specific gravity of 2.66. Its extraction is considered to be one of the most difficult processes in metallurgy. It would provide a superlight-weight metal if the problem of raw-material supply could be solved. The small amounts available have been of great value in the development of atomic energy. The chief use of beryllium is in the manufacture of a beryllium-copper alloy. The master alloy commonly contains 4 per cent beryllium. The final alloys may contain from 0.3 to 2.5 per cent beryllium. These alloys have excellent conductivity for electricity and by heat-treatment produce a material with remarkable fatigue strength. They are useful in electrical equipment and also may be employed as a nonsparking tool where the use of steel would be hazardous. The scientific uses of the metal in X-ray tubes and fluorescent lamps is increasing.

TABLE 3. WORLD PRODUCTION OF BERYLLIUM CONCENTRATES (BERYL), METRIC TONS^a

Area	1940	1941	1942	1943	1944	1945	1946
Argentina.....	520	2,186	925	881	342	40 ^b	130
Australia.....	2	3	.....	534	417	47	19
Brazil, exports.....	1,472	1,703	1,634	2,027	1,185	510	1,294
India.....	53	^d	121	1,486	508	108	100 ^c
Madagascar.....	^c	^c	^c	67 ^c	50	10 ^b	^c
Portugal.....	^c	35	^c	14	60 ^b	9	^c
Portuguese East Africa..	^c	^c	8	6	3	2	22
Spain.....	4	^c	^c	^c	^c	^c	^c
South-West Africa.....	^c	20	39	36	1	5	
Uganda.....	^c	^c	^c	.....	18	^d	^c
Union of South Africa ^d ..	5	^c	38	86	^d		
United States, mine shipments.....	110	143	244	323	352	35	91
World total (estimate) ^f	2,161	4,090	2,971	5,374	2,996	770	1,700

^a Some beryl may be produced in France, Finland, Kenya, Korea, Norway, Rumania, and U.S.S.R.

^b Estimate.

^c Data not available.

^d Less than 1 ton.

^e Estimate based on United States imports.

^f Estimate exclusive of U.S.S.R. Production in other countries for which data are not available is believed to be negligible, except Korea, whose production was 60 tons in 1944.

In 1950, beryl, running from 10 to 12 per cent BeO, was quoted at \$25.00 to \$30.00 per unit, fob mines. A 10 per cent ore, therefore, would be worth around \$275 per ton. The beryllium-copper alloy was quoted at \$24.50 per pound of contained beryllium, copper at the market.

OTHER BERYLLIUM MINERALS

Chrysoberyl is found in orthorhombic crystals, frequently twinned to form heart-shaped or pseudohexagonal forms. *Specific gravity*, 3.5 to 3.8. *Hardness*,

8½. *Color*, commonly varying shades of green, sometimes red in transmitted light. The mineral has not been found in tonnage, and its only significant use is as a gem stone. *Cat's-eye* is the name applied to a yellowish-green variety. When cut cabochon, light seems to be concentrated in a line extending across the surface of the stone. This type is found in Brazil, Ceylon, and China. It enjoys some popularity as a precious stone. *Alexandrite* is the term applied to a strongly pleochroic variety. This stone is green by daylight but appears red by artificial illumination. It has been found in the Ural Mountains, Ceylon, and Tasmania. It is a highly prized precious stone and fine specimens have been sold at prices ranging up into hundreds of dollars per carat. Chrysoberyl has been found in the pegmatites of New England and New York. It is of no importance as a source of beryllium.

Phenacite occurs at times in well-formed hexagonal crystals with a hardness of 7½ to 8 and a specific gravity of 3.0. It is found in metamorphic rocks but more commonly in pegmatites associated with quartz and feldspar. It is similar to quartz in appearance and may be present in larger amounts than recognized due to confusion with that common mineral. Specimens have been found in Maine, Colorado, Brazil, and doubtless in other pegmatitic areas. Production has been restricted to museum specimens.

Helvite is known to occur in a number of countries and in several states, but it did not attract attention as a source of beryllium until 1941, when it was found widely spread at Iron Mountain, N.Mex.¹⁴ The mineral is found here in a contact-metamorphic mass of considerable size. Since helvite contains about 13 per cent BeO it was hoped that this occurrence would prove to be of commercial interest. Helvite contains some iron and zinc in addition to manganese; indeed, it is the first member of an isomorphous series: helvite, $Mn_4Be_3Si_3O_{12}S$; danalite, $Fe_4Be_3Si_3O_{12}S$; and genthelvite, $Zn_4Be_3Si_3O_{12}S$. Helvite is isometric and brittle. *Hardness*, about 6. *Specific gravity*, varying around 3.3. *Color*, commonly red to brown, although yellow specimens have been encountered. *Index of refraction*, around 1.746. Its close resemblance to garnet is probably responsible for the fact that it was not recognized earlier.

Vesuvianite. This mineral is described in the section devoted to it. It is of interest that a mineral not commonly considered to contain beryllium may include considerable amounts.

Future Sources. As has been indicated, the major problem of the beryllium industry is to increase the supply of raw materials. Several possibilities exist. New discoveries of beryl-rich pegmatites may be made in areas not now explored. Massive beryl may be recognized in areas now known where it has been ignored due to its lack of conspicuous characteristics (on some weathered exposures it assumes the color of the surrounding rocks and is not readily recognized). A disseminated deposit of beryl may be found in which it occurs as small crystals. Some of the rare beryllium minerals may be found in tonnage. Minerals may be discovered in which beryllium is not a normal constituent but has been introduced in the crystal structure. Beryllium is not recognized easily and frequently is included by the analyst with aluminum, which it resembles in chemical behavior. An expanding knowledge of crystal chemistry shows that beryllium might replace

silicon, phosphorus, and manganese. The possibility of the discovery of beryllium in minerals with which it not commonly associated, therefore, is worthy of attention.

Emeralds of gem quality up to 200 carats in weight are reported to have been synthesized from extremely pure alumina, beryllia, and silica, with traces of chromic oxide and ferric oxide as coloring matter.²⁰

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BORAX AND BORATES

Although there are over 60 minerals containing boron, including a dozen or more with a high enough boron content to be considered as possible sources of this element, only a very few are or ever have been important commercial sources. The relative importance of these minerals has varied greatly with the discovery and opening of new deposits and the forced closing down of old ones. Thus, when the first edition of this book was in preparation colemanite and ulexite had, for many years, been the most important world sources of borax. Since the discovery of the immense kernite-borax deposits near Kramer County, Calif., in 1925 and their rapid development, plus the large-scale extraction of borax from Searles Lake and Owens Lake, California, brines have completely changed the picture not only in this country but also in the world industry. Other sources could not compete, and today the California sources noted above supply most of the world's demand for borax and borates. Space cannot be given here to the historical development of the industry, and only the present and probable future sources of borax will be covered.

With two exceptions, all natural borate minerals of any importance are hydrous borates with 4 to 16 molecules of water of crystallization. They are simple borates of sodium or calcium or both, except for the unimportant bakerite and howlite, which also contain silica. The two exceptions first noted are sassolite (natural boric acid) and boracite (magnesium borate and chloride).

Much confusion has arisen concerning the nomenclature of the borate minerals, and many incorrect synonyms have been widely used. Schaller¹⁰ has done much to correct this situation by publishing the following definitions:

<i>Accepted Name</i>	<i>Incorrect Synonym</i>
Borax.....	Tincal, prismatic borax, sodium biborate, sodium tetraborate
Kernite.....	Rasorite
Ulexite.....	Boronatrocalcite, natroboracalcite, hayesine, franklandite, cryptomorphite, tiza, tincalzit, borate of lime, cotton-ball, sheet cotton
Boracite.....	Stassfurtite
Priceite.....	Pandermite
Probertite.....	Boydite, kramertite
Tincalconite.....	Octahedral borax, mohaveite

The following minerals are or have been important commercial sources of the borates.

BORAX (TINCAL)

Composition. Borax is sodium tetraborate, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, or $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$: B_2O_3 , 36.6 per cent; Na_2O , 16.2 per cent; H_2O , 47.2 per cent. When calcined, 69.2 per cent B_2O_3 .

General Description. Borax occurs as short, stout, white monoclinic prisms, in solution in saline lakes, as a glistening white efflorescence or constituent of certain alkali soils, and as compact glossy masses.

Physical Properties. *Hardness*, 2.0 to 2.5. *Specific gravity*, 1.69 to 1.72. *Melting point*, at 1 to 1.5 in scale. *Index of refraction*, 1.447 to 1.472. *Color*, white to grayish, greenish, or bluish. *Streak*, white. *Luster*, vitreous to dull. *Transparency*, translucent to opaque. *Tenacity*, brittle. Readily soluble in water. Sweetish, alkaline taste. Crystals effloresce, losing $5\text{H}_2\text{O}$ below 100°C ; sixth molecule of H_2O at 100°C ; seventh and eighth molecules at 130°C ; ninth, at 150°C ; and tenth, at 160°C or above; 300°C necessary to ensure complete desiccation.

KERNITE (RASORITE)

Composition. Kernite has exactly the same chemical composition as borax except that it has only 4 molecules of water instead of 10. Its formula is $\text{Na}_2\text{B}_4\text{O}_7 \cdot 4\text{H}_2\text{O}$ or $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O}$: B_2O_3 , 51.1 per cent; Na_2O , 22.6 per cent; H_2O , 26.3 per cent. When calcined, 69.2 per cent B_2O_3 .

General Description. Kernite occurs in transparent, colorless monoclinic crystals up to several feet in diameter or in large cleavable masses somewhat resembling the selenite variety of gypsum. It is often mixed with borax or with sediments. It has two good cleavages that result in fibrous particles.

Physical Properties. *Hardness*, 2.5. *Specific gravity*, 1.95. *Melting point*, 1 to 1.5 in scale. *Index of refraction*, 1.454 to 1.472. *Color*, colorless when pure. *Streak*, white. *Luster*, vitreous or silky. *Transparency*, transparent to translucent. *Tenacity*, brittle. Soluble slowly in cold water, but readily in hot.

COLEMANITE

Composition. Colemanite is calcium borate, $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$ or $2\text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$: B_2O_3 , 50.9 per cent; CaO , 27.2 per cent; H_2O , 21.9 per cent. When calcined, 65.2 per cent B_2O_3 .

General Description. Colemanite occurs in short, prismatic white crystals (resembling datolite); in loosely compacted, white, chalky masses; and in firm, white, compact, porcelainlike masses.

Physical Properties. *Hardness*, 4.0 to 4.5. *Specific gravity*, 2.26 to 2.48. *Melting point*, at 1.5 in scale of fusibility. *Index of refraction*, 1.586 to 1.614. *Color*, white or colorless. *Streak*, white. *Luster*, vitreous to dull. *Cleavage*, perfect clinopinacoidal. *Fracture*, uneven to subconchoidal. *Transparency*, transparent to opaque. *Tenacity*, brittle. *Decrepitates*, intumesces, and fuses easily on heating. Insoluble in water, but easily soluble in hot hydrochloric acid.

ULEXITE (BORONATROCALCITE)

Composition. Ulexite is a borate of sodium and calcium, $\text{CaNaB}_5\text{O}_9 \cdot 8\text{H}_2\text{O}$ or $2\text{CaO} \cdot \text{Na}_2\text{O} \cdot 5\text{B}_2\text{O}_3 \cdot 16\text{H}_2\text{O}$: B_2O_3 , 43.0 per cent; CaO , 13.8 per cent; Na_2O , 7.7 per cent; H_2O , 35.5 per cent. When calcined, 66.6 per cent B_2O_3 .

General Description. Ulexite occurs in white, rounded masses ("cotton balls"), composed of loosely compacted, fine silky fibers, easily pulverized between the fingers.

Physical Properties. *Hardness*, 1. *Specific gravity*, 1.96. *Melting point*, at 1 in scale of fusibility with intumescence. *Index of refraction*, 1.491 to 1.520. *Color*, white. *Streak*, white. *Luster*, silky. *Cleavage*, fibrous. *Transparency*, translucent. *Tenacity*, brittle. *Insoluble* in cold water; slightly soluble in hot water; soluble in acids.

BORACITE (STASSFURTITE)

Composition. Boracite is magnesium borate and chloride, $\text{Mg}_7\text{Cl}_2\text{B}_{16}\text{O}_{30}$ or $6\text{MgO} \cdot 8\text{B}_2\text{O}_3 \cdot \text{MgCl}_2 \cdot \text{B}_2\text{O}_3$, 62.37 per cent; MgO , 27.00 per cent; MgCl_2 , 10.63 per cent.

General Description. Boracite occurs in small, hard, glassy, isometric crystals, or in white, rather soft masses (stassfurtite variety).

Physical Properties. *Hardness*, 7 (crystals); 4.5 (masses). *Specific gravity*, 2.9 to 3. *Melting point*, 2 in scale. *Index of refraction*, 1.662 to 1.673. *Color*, white to yellowish or greenish. *Streak*, white. *Luster*, vitreous. *Transparency*, transparent to opaque. *Tenacity*, brittle.

SASSOLITE (NATURAL BORIC ACID)

Composition. Sassolite is boric acid, $\text{H}_3\text{BO}_3 \cdot \text{B}_2\text{O}_3$, 56.4 per cent; H_2O , 43.6 per cent.

General Description. Sassolite occurs chiefly in solution or in vapors near volcanoes or hot springs; also in small white or yellowish scales.

Physical Properties. *Hardness*, 1. *Specific gravity*, 1.43. *Melting point*, at 0.5 in scale. *Index of refraction*, 1.340 to 1.459. *Color*, white or yellowish. *Streak*, white. *Luster*, pearly. *Transparency*, translucent. *Tenacity*, brittle. Readily soluble in water. Sour or acid taste.

PRICEITE

Composition. $5\text{CaO} \cdot 6\text{B}_2\text{O}_3 \cdot 9\text{H}_2\text{O} \cdot \text{B}_2\text{O}_3$, 48.7 per cent; CaO , 32.5 per cent; H_2O , 18.8 per cent. When calcined, 60 per cent B_2O_3 . A massive, friable, chalky mineral once considered as merely a chalky variety of colemanite, mined in Turkey, and once produced on a small scale in Curry County, Oreg.

Geological Occurrence of Borates. Commercial production of borates in the past has come from a wide variety of deposits. In approximate order of importance these types are:

1. *Old Lake Beds, Recrystallized.* The largest and most important borate deposits in the world, those of the Kramer District in Kern County, Calif., are unique in several ways. One of the two chief minerals, kernite, was first found here. They are the only borate deposits of this general type that do not contain other salines, such as sulfates, chlorides and carbonates of lime, soda, potash, and magnesium. These deposits are regarded as old lake beds in which were concentrated and recrystallized sodium borate leachings from other deposits of ulexite.

2. *Alkali Lakes.* Searles Lake, Calif., is the outstanding example of concentrated, complex brines in an old lake bed with a hard surface crust that is now an important source of borax as well as potash and sodium salts (see page 400).

3. *Old Lake Beds.* In this type of deposit, borates, chiefly colemanite, occur in bedded deposits with other sedimentaries, such as gypsum, limestones and shales. The origin of deposits of this type is generally ascribed to the action of boric acid solutions or vapors, resulting from volcanic activity, upon beds of limestone or gypsum. Examples: the colemanite deposits of Death Valley and elsewhere in the Great Basin of California and of the Muddy Mountains district of Nevada; and the Turkish deposits of priceite near Panderma, Asia Minor.

4. *Borax Marshes or Dry Lakes.* The borax marsh deposits of California, Nevada, and Oregon consist chiefly of ulexite but also contain borax (tincal). The borates were probably derived by the leaching of other borate minerals from a higher elevation. The ulexite deposits of the lagoons and "salares" of Ascotan in the Atacama district of Chile and elsewhere in Chile, Peru, Bolivia, and Argentina are probably of similar origin. The borax (tincal) of Tibet is derived from salt lakes, which probably obtained their borax content from volcanic sources.

5. *Volcanic Vapors.* The fumaroles, soffione or gaseous emanations of Tuscany, Italy, contain boric acid (sassolite), which is recovered commercially by solution in water.

6. *Hot Springs in Volcanic Regions.* Hot springs in Tuscany, Italy, contain sassolite. Hot springs deposit colemanite in Chile, at Baños del Toro; and borax (tincal) in California, Nevada, and the Puga Valley of Ladakh, Kashmir, India. Mud volcanoes of Kertch and Taman, southern Russia, also deposit borax.

7. *Marine Borates.* The complex salt deposits of the Stassfurt district of Germany, regarded as of marine origin, contain boracite.

In most cases, with the possible exception of the marine borate deposits, the boron is believed to have been of volcanic origin. Probably it was evolved as boric acid, in volcanic vapors and hot springs, which reacted with lime and soda in volcanic ash and clay, forming sodium and calcium borates. These minerals, through solution, transportation, redeposition, concentration, and recrystallization, eventually formed the deposits of the several types noted.

Distribution of Deposits and Methods of Working. While deposits of borate minerals are not too scarce throughout the world the economic conditions of price and demand have encouraged important commercial production in only a few countries. Thirty-five years ago production in Chile and the United States was nearly equal at about 50,000 tons per year each. A few other countries (Italy, Turkey, Peru, and Argentina) produced from a few hundred to a few thousand tons per year. Gradually United States production pulled ahead, with the discovery of larger and more cheaply mined deposits. The large-scale development of the Kramer, Calif., deposits, beginning in 1926, and the great increase in demand starting about 1933, so greatly increased production and lowered costs that competition in other countries sharply declined and, since about 1929, this country has produced from 90 to 95 per cent or more of the world's borate minerals. All this production now comes from California, chiefly from the Kramer deposits and from Searles Lake. The tremendous reserves in these two areas make it probable that they can satisfy the world's demands for a great many years and that we need not in the foreseeable future again draw upon other deposits which may have been known or worked in the past.

United States. California. In recent years borate production has come entirely from four areas: Searles Lake brines (two producers), Owens Lake brines (one producer), the kernite-borax deposits of the Kramer district (one producer), and massive colemanite deposits near Shoshone, Inyo County (one producer).

The oldest and largest producer, the Pacific Coast Borax Co., operates the kernite-borax deposits from headquarters at Boron in the Kramer District of Kern County and a borax refinery at Wilmington, Calif., where over 200 boron derivatives are made. The Kramer deposits, described in detail by Gale,⁷ do not outcrop but were discovered by drilling. Gale states:

As developed by drilling and mining, the borate deposits lie within an irregularly oval area about 4 miles in length from east to west and 1 mile in width from north to south. . . . The principal borate deposits range in depth from about 300 to 1,000 ft below the surface of the ground. . . . The deposits of the two sodium borate minerals, tincal or native borax, and kernite, found later, have proved to be by far the most important, and have yielded almost the entire output from the district. These deposits of massive crystalline sodium borate, containing subordinate amounts of clay as gangue or other impurities, occur in the form of tabular beds or layers more or less interbedded with sediments, ranging up to a total of 250 ft in thickness at places.

As to reserves he states that about 2 million short tons of sodium tetraborate (based on 40 per cent anhydrous boric acid, B_2O_3) had been mined in the 20 years from 1926 to 1946, and that "reserves available for future production have not as yet been fully disclosed, but they are very great, probably at least 50 times the amount already taken out, and possibly much more than that."

The ore is mined by underground methods. While the borax and kernite could, in most cases, be mined separately it has been found better to mine and mix them together, since the granular grains of borax keep the fibrous, cleavage grains of kernite from clogging grinding equipment. The crude ore, containing about 29 per cent B_2O_3 (due to contamination with clay and shale), is ground, calcined, and concentrated to a product running about 45 per cent B_2O_3 and then shipped to the refinery at Wilmington, Calif. Here it is dissolved under pressure in hot water, filtered to remove solid impurities, and crystallized into pure borax.¹

At Searles Lake, San Bernardino County, there are two operators recovering borax: American Potash and Chemical Co. at Trona and West End Chemical Co. at West end. Both companies obtain their borax from the lake brines, but the former and much larger operation also recovers potash and sodium salts as well as bromine and lithium compounds. The operations are described in more detail under Potash Salts. The brine contains about 36 per cent total salts, of which about 2.84 per cent is borax and the balance mainly chlorides, sulfates, and carbonates of potash and sodium. The brines are first concentrated by evaporation in vacuum pans and then the various end products, including borax, are separated by fractional crystallization. Borate products made here are crystalline borax in several finenesses, dehydrated borax, and boric acid.

At Owens Lake,⁵ Inyo County, there are three plants, only one of which at

present recovers borates. This plant, operated by the Columbia Chemical Division of the Pittsburgh Plate Glass Co., recovered nearly 1,000 tons of borax in 1946, with a much larger production of sodium carbonates. The other two producers, Wyandotte Chemical Co. and Permanente Metals Corp., recover and ship only sodium carbonates, but the former company produced borax experimentally in 1946. The brines here, resembling those of Searles Lake, but less concentrated and consisting predominantly of sodium salts, contain around 2.5 per cent borax.

The United States Borax Co. operates colemanite deposits near Shoshone, Inyo County. Their output, relatively small compared with that of the leading producers, is processed to yield borax at a nearby refinery.

Other California deposits of historical or possible future importance, such as those 5 miles south of Lang, Los Angeles County, and the Russell mines near Stauffer, Ventura County, but not now operated, cannot be described here.

Nevada. The large deposits (White Basin and Callville Wash) of massive colemanite in the Muddy Mountains district east of Las Vegas, Clark County, once of considerable importance and described in some detail in the first edition of this book, are no longer operated. Other borate deposits in Clark, Esmeralda, and Mineral counties are well known and may have future commercial importance, but they cannot now compete with the California deposits.

Other Countries. Chile. Once one of the world's largest producers, Chile has nearly ceased production, reporting shipments of less than 500 tons in 1945, but deposits are numerous and extensive. In 1946 reserves of over 20 million metric tons were reported⁶ in the provinces of Tarapaca, Antofagasta, and Atacama. Most of the deposits are of the dry lake-bed type, with ulexite the predominating mineral. It is also noted that the nitrate plants could also produce borax as a by-product. Under present conditions it is felt that none of the Chile deposits can compete with California in the world's markets.

Argentina. For many years a producer of only 1,000 or 2,000 tons per year, largely for local consumption, Argentina increased her production for export in the 1930's and reached a level of around 11,000 tons. In 1946 it was reported that in recent years production has averaged around 9,000 tons per year.

Turkey. Prior to the Second World War, Turkey was the world's third largest producer of borates, shipping 5,000 to 7,000 tons per year of priceite (incorrectly called "pandermite"), largely as crude for export. During the war the mines of Sultancayiri at the Kaza of Susurluk of the Province of Balikkessir produced only 300 to 400 tons per year, due to difficulties of export.

Italy. Italy's output of borates, while in normal times amounting to only 6,000 to 7,000 tons per year, is unique in that it produces crude boric acid (salsolite) from volcanic gases or vapor springs called "soffioni." At Laidereello and elsewhere in the province of Pisa these vapors yield natural steam for heat and power, ammonia, carbon dioxide, and crude boric acid.

Other countries that produce a few hundred tons of borates per year are Germany, Peru, Bolivia, Tibet, Persia, Ceylon, and India. In 1934 it was reported that deposits of "hydroborite," $\text{CaO} \cdot \text{MgO} \cdot 3\text{B}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$, mixed with clay and gypsum had been discovered in western Kazakhstan, Russia, and commercial produc-

SALIENT STATISTICS OF THE BORON-MINERAL INDUSTRY IN THE UNITED STATES, 1943 TO 1948

	1943	1944	1945	1946	1947	1948
Sold or used by producers:*						
Short tons:						
Gross weight.....	256,633	277,586	325,935	430,689	501,935	450,932
B ₂ O ₃ content.....	87,600	91,700	104,600	129,800	145,700	134,700
Value.....	\$6,401,507	\$6,579,587	\$7,635,365	\$9,575,866	\$11,844,108	\$11,147,735
Imports for consumption (refined):†						
Pounds.....	.....	.....	1,344	100,567	2,000	3,056
Value.....	.....	.....	\$491	\$4,077	\$747	\$1,503
Exports:						
Short tons.....	26,877	32,759	43,577	53,303	85,736	70,940
Value.....	\$1,282,372	\$1,601,014	\$2,064,065	\$2,644,760	\$4,651,642	\$4,075,049
Apparent consumption, ‡ short tons.....	229,756	244,827	282,359	377,436	416,200	379,994

* 1941: Borax, kernite, boric acid, and colemanite; 1942 to 1945. Borax, anhydrous sodium tetraborate, kernite, boric acid, and colemanite.

† Also 525 lb of crude valued at \$7 in 1943.

‡ Quantity sold or used by producers plus imports minus exports.

tion had started, but that little was known of the development. This is doubtless the occurrence of hydroboracite in the Caucasus noted by Dana.*

Production and Consumption. The table on page 113, compiled by the U.S. Bureau of Mines, shows the United States production and consumption of borate minerals.

In view of the small production of borates in other countries and the large exports from this country it is evident that we not only produce but also consume the bulk of the world's borate production.

Refining of Borates. Part of the production of borates is marketed as crude borax or crude kernite, part is refined as it is recovered (as from the Searles Lake brines), and part (such as crude colemanite) must be refined before marketing.

Borax is commonly made from colemanite by treatment with solutions of sodium carbonate or sodium sulfate. The resulting borax is soluble in water, while the calcium carbonate or sulfate is insoluble and a separation may be made by filtration or decantation. The borax may then be crystallized from solution by evaporation. Crude borax or kernite may be refined by solution, filtration, or decantation, and recrystallization. Anhydrous borax is made by partial calcination of borax followed by complete fusion. The molten borax is poured into iron molds, cooled, crushed, ground, and screened. Boric acid is made by treating ground borates with sulfuric acid.

Markets and Prices. The principal product marketed is borax. This may be used as such or employed as a raw material for the manufacture of many boron compounds. In early 1950, fine granular borax was quoted in bulk at works at \$57.25 per ton. Borax of technical grade, 99½ per cent, in paper bags, in carload lots at works was quoted at \$74.50 per ton. Borax is generally available in wholesale quantities from storage in Chicago and New York.

Utilization. The principal properties on which depend the uses for borax and the borates are very easy fusibility and high fluxing ability, high solubility and detergent properties, and ability to impart desirable properties to glass.

Some years before the Second World War the chief industrial use for borax was in making ceramic enamels and glazes for sheet metal, cast iron, brick, tile, terracotta, glass, etc. The enameled kitchenware, stove, refrigerator, and washing-machine industries took the bulk of the tonnage. Today by far the largest use is in the glass industry, particularly container glass. This is due in part to greatly increased use in glass and in part to the shortage of sheet iron and steel for enamel ware during and after the war.

A very good outline of the use of borax as given by R. M. Curts† is reproduced in Fig. 4.

In glass, borax has two major and many minor uses. In lime-soda glasses, used for containers, tableware, etc., around 1 per cent B_2O_3 is added to the batch to improve melting and fining conditions and to increase clarity, brilliance, strength, and resistance to thermal shock. In borosilicate heat-resistance glasses, such as Pyrex laboratory and ovenware, 12 to 14 per cent B_2O_3 forms an essential

* DANA, JAMES, and SALISBURY, EDWARD, "The System of Mineralogy," 7th ed., John Wiley & Sons, Inc., New York, 1944.

† Borax, *Chem. Inds.*, Vol. 47, No. 4, pp. 366-373, October, 1940. This article gives the best recent summary of the uses of borax and the borates.

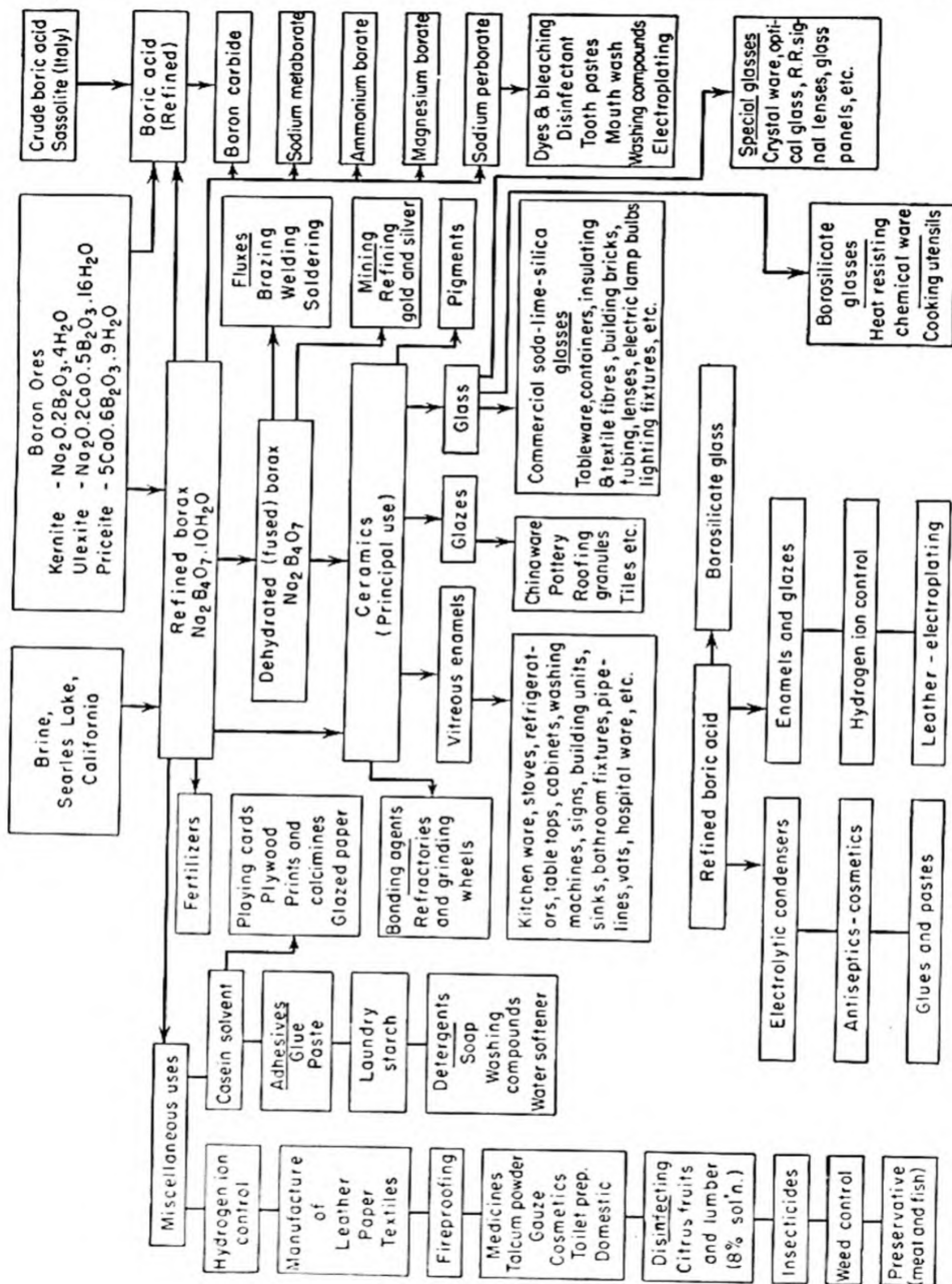


Fig. 4. Various uses of refined borax and boric acid.

part of the batch. These glasses possess a low coefficient of expansion and are highly resistant to thermal and mechanical shock and to chemical action. Other uses in the glass industry are for making optical glass, electrical insulators, building blocks, glass wool, etc.

In other ceramic applications its low melting point and fluxing ability are utilized in making low-melting-point glazes and enamels, in ceramic coatings for prepared roofing granules, in ceramic bonds for abrasive and refractory grains, and in making fused ceramic colors or frits. Borax may constitute 25 to 40 per cent of the batch in making sheet-iron enamels.

In metallurgical processes borax is used as a flux in refining gold, silver, and nonferrous alloys and in fluxes for welding, soldering, and brazing, where its solvent effect on metallic oxides is also utilized.

In agriculture borax has become recognized as an essential ingredient of fertilizers used on boron-deficient soils, which are more widespread than has been generally supposed. Its use eliminates many forms of deficiency plant diseases, such as heart and crown rot in sugar beets, brown heart in turnips, cracked stems in celery, etc. It is also used in insecticides, as a weed killer, as a disinfectant wash for citrus fruits to prevent "blue mould," and in the control of sap stain in the lumber industry.

As a mild detergent borax and borates are used in soaps, cleaners, washing compounds, high-gloss laundry starches, etc. Sodium perborate has both a detergent and a mild bleaching action.

Its mildly alkaline reaction and its detergent, buffering, and even bleaching properties are useful in a wide variety of applications where one or more of these properties are essential. Thus, it is used in several operations in leather tanning, textile finishing, and water softening; as a solvent for casein in paper coating; as a preservative in adhesives, starches, and sizes; as a corrosion inhibitor; and for many other uses.

In the cosmetic industries its antiseptic and detergent properties are used in powders, creams, ointments, gauzes, lotions, mouth and eye washes, and similar preparations.

An interesting but minor use is in the manufacture of boron carbide described in the chapter on abrasives.

The beneficial effects of the use of boron in steel was so completely demonstrated in 1942 that the future use of this element as a ferroalloy component was assured. Boron increases the hardenability of steel, its ultimate strength, and its elastic limit. The amount of boron used is small, and the percentage in steel is restrained to a maximum of 0.003 per cent. The use of boron may replace several hundred times its weight of other alloy elements such as nickel, chromium, and vanadium. It cannot eliminate the use of such elements, since there is a limit to the increase in hardenability that it supplies, and it does not furnish all the qualities to steel obtainable from these alloying metals. Ferroboron has been manufactured to the extent of over 100 tons per year. It has sold for \$1.30 per pound for material containing a minimum of 17.5 per cent boron.

Boron has a remarkable capacity to absorb neutrons; therefore, it must be entirely absent from the graphite employed in uranium fission. The same charac-

teristic makes boron useful in the operation of uranium-graphite piles employed in the production of plutonium. Steels containing boron were used for this purpose.

Borax is one of the most versatile of our chemicals and is used in minor amounts in a wide variety of other industries, ranging from the manufacture of candles and stove polish to tobacco.

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BROMINE

General Description. Bromine is a reddish-brown liquid, the only element, other than mercury, that is liquid at ordinary temperatures. It was discovered in 1826, and enough interest was aroused in this element so that a small production was initiated in the United States in 1849 in the saltworks at Freeport, Pa.

Physical Properties. Atomic weight, 79.92. Melting point, -7.3°C . Boiling point, 58.8°C . Specific gravity, 3.1833.

Occurrence. Bromine does not occur free. It is found in a few rare minerals such as bromyrite (AgBr) and embolite (AgClBr). It is found in sea water in a small percentage and in concentrated saline lakes such as the Dead Sea in far greater quantities. Where such waters have evaporated and the soluble salts precipitated, bromine is found in some quantity in the minerals formed. The potash salts of Stassfurt, Germany, are reported to contain up to 0.2 per cent bromine. Some of this is recovered during the treatment of the salts for commercial potash. Early bromine production in the United States was restricted to recovery from the bitterns left after the extraction of salt from brines produced in Ohio, West Virginia, and Michigan. This source was supplemented by additional production from the complex brines at Searles Lake, Calif., and from sea-water bitterns in the same state. Rising demands for bromine, caused by its use in antiknock compounds in gasoline, resulted in the exploitation of the largest and most widely distributed occurrence of all, the ocean.

Production. The common process for the extraction of bromine involves the oxidation of the brine, removal of the liberated bromine by air, and its absorption with an alkali carbonate solution from which it can be recovered in the form desired. Various modifications involving the use of chlorine, sodium chlorate, and manganese dioxide have been employed. The first plant to utilize the brines of the ocean was constructed at Wilmington, N.C., in 1933. A second plant was erected at Freeport, Tex. The Wilmington plant was transferred to Freeport in 1947.

In the location of a sea-water plant it is essential to discharge the debrominated water in such a manner that it cannot dilute the intake. The plant at Wilmington, N.C., was built on a peninsula to allow for this. The sea water, containing 67 ppm of bromine, or 1 lb in 2,000 gal, moved through a canal to the plant. At this point a calculated amount of 10 per cent sulfuric acid was added and chlorine introduced. The bromine, liberated by the chlorine, is blown out by air. The water deprived of its bromine flows to waste. The bromine is absorbed by soda ash forming sodium bromide and sodium bromate. The solution containing these

BROMINE AND BROMINE IN COMPOUNDS
SOLD OR USED BY PRODUCERS IN THE
UNITED STATES
(Source: U.S. Bureau of Mines)

Year	Pounds	Value
1943	94,085,937	\$19,107,065
1944	102,112,462	19,712,819
1945	79,709,857	14,796,229
1946	42,783,327	8,560,434
1947	78,177,650	14,837,104
1948	76,147,551	14,844,152

compounds is treated with sulfuric acid. The bromine vapors produced by this treatment are steamed out and concentrated to liquid bromine.

The production of bromine in recent years is reported in the accompanying table.

Palestine. The complex and concentrated brines of the Dead Sea are being processed for the recovery of their potash content. Bromine is recovered as a by-product. The brines are subjected to solar evaporation, which results in the precipitation of

potash in the form of carnallite, which is treated further to produce potassium chloride. After the removal of the carnallite the residual brine is treated with

steam and chlorine. Bromine is liberated, separated from its associates, and bottled for shipment. At a depth of 5 m the waters of the Dead Sea are reported to carry 3.0 g per l of magnesium bromide. The total amount of this salt existing in the Sea is estimated at 980 million tons.

Utilization. Bromides have a long-established usage in medicine. Silver bromide is sensitive to light and is manufactured into the emulsions employed to coat photographic paper and film. It is also used in the manufacture of certain dyes and chemical reagents. The largest consumer is in the manufacture of ethylene dibromide, and a large portion of the total production is sold in this form. Ethylene dibromide is mixed with tetraethyl lead to produce ethyl gasoline anti-knock compound. Ethylene dibromide has been found to be useful in soil fumigation, and the productivity of badly infested soils has been restored to normal by its administration. Methyl bromide has proved useful as a fumigating agent, particularly for food processing where it has the advantage of being active at low temperatures and leaving no taste or odor. Bromine was quoted in early 1950 at 21 cents per pound in carloads.

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BRUCITE

Composition. Brucite is magnesium hydroxide, $\text{Mg}(\text{OH})_2$: MgO , 69.0 per cent; H_2O , 31.0 per cent; Mg, 41.4 per cent.

General Description. Brucite is a soft, waxy, translucent mineral, often closely resembling various types of talc, but slightly harder. May be foliated, fibrous, or massive; also in tabular hexagonal crystals.

Physical Properties. *Hardness*, 2.5. *Specific gravity*, 2.38 to 2.4. *Melting point*, above 6 in scale of fusibility. *Index of refraction*, 1.559 to 1.580. *Color*, various shades of green, white, bluish. *Streak*, white. *Luster*, pearly or waxlike. *Cleavage*, basal; uneven fracture. *Transparency*, translucent. *Tenacity*, sectile and flexible.

Occurrence. Brucite usually occurs in dolomite or serpentine with magnesite and/or hydromagnesite. The largest known deposit is that at Gabbs Valley, Nevada.² These deposits, discovered in 1927 but not worked on an important scale commercially until about 1934, are located in the Luning District on the northwestern slope of the Paradise Range in northwestern Nye County, about 200

miles south of Reno. Here are huge masses of brucite associated with large deposits of magnesite and dolomite, in places altered to hydromagnesite. Extensive exploration and development during the Second World War disclosed brucite reserves estimated at over 71 million tons. Prior to and since the war shipments have been made to Ohio for calcining and for mixing with dead-burned dolomite for basic open-hearth dressings and ramming mixes. During the war the greatest development was of the associated magnesite, which was mined on a very large scale for making metallic magnesium near Las Vegas, Nev.

Near Chewelah, *Washington*, massive brucite occurs in considerable quantities associated with magnesite. Since it was originally thought to be marble, attempts were made to work it as an ornamental stone, but it is too soft for exterior use. Portions of it, light green in color, resemble jade and it is carved and turned locally into candlesticks, cups, plates, and ornaments. In recent years it has been used to some extent with magnesite as a refractory material.

Canada. Commercial deposits of brucite were first discovered in Canada in 1937 at Rutherglen in the Nipissing district of Ontario.^{1,3,4,5} Later, similar deposits were discovered near Wilkinson, Ontario, and in the Bryson and Wakefield areas of Quebec. In these deposits the brucite occurs as small crystals or granules disseminated in limestone and composing 25 to 30 per cent of the rock mass. By a system of calcination, hydration, and separation, worked out by the Canadian Bureau of Mines, this ore is made to yield calcined brucite granules analyzing 94.4 per cent MgO with only 0.40 per cent CaO and 4.38 per cent water. These deposits have become an important source of magnesite refractories in Canada, being especially suited for high-grade brick.

See also Magnesite and Magnesium Compounds.

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CALCITE

Composition. Calcite is calcium carbonate, CaCO_3 :CaO, 56.0 per cent; CO_2 , 44.0 per cent. Sometimes it is very pure and sometimes part of the calcium is replaced by magnesium, iron, or manganese. It is often mixed with impurities, such as silica, clay, organic matter, limonite, or hematite.

General Description. The mineral calcite occurs in a great variety of crystal forms of the hexagonal system, and is transparent, translucent and opaque, from white through nearly all colors to black. The crystals are always characterized by a perfect rhombohedral cleavage. More commonly the mineral occurs not in definite crystals, but as limestone or marble in crystalline masses, veins and beds; as stalactites and stalagmites; as linings of caves and fissures, from coarsely crystalline to finely granular; also in lamellar, fibrous, compact, porous or earthy masses; sometimes oölitic or pisolitic.

Aragonite has the same chemical composition as calcite, but it crystallizes in the orthorhombic system, often in radial, columnar, or fibrous aggregates. It has a hardness of 3.5 to 4; a specific gravity of 2.9 to 3; imperfect prismatic cleavage; and conchoidal fracture. Otherwise it resembles calcite, but effervesces with acids less easily than calcite. Commercially, it has no uses distinct for those of other forms of calcium carbonate.

Physical Properties. *Hardness*, 3.0. *Specific gravity*, 2.71 to 2.72. *Melting point*, at about 825°C it decomposes, giving off CO_2 , leaving CaO (or lime), which melts at about 2570°C . *Index of refraction*, 1.486 to 1.658. *Color*, colorless, white, through practically all colors to nearly black. *Streak*, white. *Luster*, vitreous to dull and earthy. *Cleavage*, perfect rhombohedral. *Fracture*, varies, dependent upon structure. *Transparency*, transparent to opaque. *Tenacity*, brittle. Perfectly transparent crystals show high double refraction. *Twinning* in crystals is common.

Calcite and other forms of calcium carbonate can always be easily recognized by a hardness of 3 and by their easy solubility, with brisk effervescence, in cold dilute acids, properties possessed by no other common minerals resembling calcite.

Varieties. Calcite, or—more properly for present purposes—calcium carbonate, occurs in a great variety of forms, the more important of which are as follows.

Crystallized calcite, including dogtooth spar, which occurs in acute, scalenohedral crystals; nailhead spar, which occurs in flat, rhombohedral crystals; satin spar (term also used for a variety of gypsum), which is fibrous and has a silky luster; Iceland spar (see below); and ordinary calcite deposited from solution as vein fillings, etc.

Massive and compact varieties, including marble and limestones.

Soft earthy types, including chalk and marl, which is an impure earthy form mixed with sand and clay, often containing organic matter and sometimes shells. It generally occurs in bedded deposits and has been used in the manufacture of portland cement and as agricultural lime. Pure, white marl has been ground and used as a substitute for whiting.

Cave deposits, including onyx marble, a banded variety, usually formed as

linings of caves; stalactites, which are iciclelike masses pendant from the roofs of caves, being formed by the dripping and evaporation of calcareous waters; and stalagmites, which are more or less conical deposits built up by water dripping on the floors of caves, usually directly beneath stalactites.

Spring and stream deposits, including travertine, which is formed in banded deposits along stream beds and around springs; and calcareous sinter and calc-tufa, which are usually porous deposits formed about calcareous mineral springs. They often contain leaves, twigs, and other organic material.

The only form of calcite or crystallized calcium carbonate which has properties and uses distinct from other forms and for which there are no entirely satisfactory substitutes in the finest of optical instruments is Iceland spar.

ICELAND SPAR

Iceland spar is the name given to a pure crystallized form of calcite that is sufficiently transparent and free from defects to be used in the manufacture of optical instruments. The actual consumption is small, but the degree of purity and physical perfection is such that suitable material can be obtained only with difficulty. The properties in Iceland spar of value are transparency, double refraction, and ability to polarize light. The latter property is employed in the construction of the Nicol prism, an indispensable component of the petrographic microscope; the saccharimeter; and similar instruments using polarized light. The Nicol prism consists of an elongated cleavage fragment of Iceland spar. The cleavage angle of 71 deg produced by the natural rhombohedral cleavage is reduced by grinding to 68 deg. The prism is then cut in two, the sides polished, and the pieces cemented with linseed oil. When light falls on the end of such a prism it is resolved into two rays, since calcite is double-refractive. Each ray is plane polarized. One ray is reflected by the cement at the junction of the two pieces of Iceland spar and emerges from the side of the prism and is lost. The other ray passes through the Nicol prism with little or no deviation and emerges as plane-polarized light. This ingenious device is utilized in pairs in the petrographic microscope and has contributed enormously to the knowledge of minerals and other crystallized materials.

Physical properties of Iceland spar that have a direct bearing on the mining methods employed are its perfect rhombohedral cleavage, a cleavage in three directions at oblique angles to each other, and its susceptibility to abrasion or scratching. The crystals cleave so readily that light blows will shatter them into fragments, and, as they are soft enough to be readily scratched with a knife, extreme care must be taken in handling them.

The minimum size for first-grade prisms is about $\frac{1}{2}$ by $\frac{1}{2}$ by $1\frac{1}{2}$ in. for one shape and $\frac{3}{4}$ by $\frac{3}{4}$ by $\frac{1}{2}$ in. for a second shape. The price per pound varies somewhat with the size of the pieces. The prices on optical spar given below are for material trimmed free of all flaws and imperfections.

The price of optical spar is dependent upon quality and perfection to such an extent that standardized quotations do not exist. During the Second World War when demand was acute material sold from \$20 to \$100 per pound, depending upon size and quality.

Defects in Iceland Spar. The common defects in Iceland spar are summarized as follows:

1. Lack of perfect transparency. Some crystals or portions of crystals show more or less cloudiness or milky turbidity. Such material is valueless for optical purposes.

2. Poor color. The best grades of Iceland spar are water clear and absolutely colorless. Some specimens, however, have a yellow color, which is not very objectionable for certain purposes.

3. Incipient cleavage cracks in the interior of some crystals. Such cracks may be due to inherent internal strains, or they may be caused by rough treatment in mining or subsequent handling. Specimens containing such cracks are valueless for optical purposes, but sometimes small, clear pieces may be obtained from between such cracks.

4. The crystals may show repeated internal twinning, the visual evidence of which usually consists of the appearance of bands of bright rainbow colors when the crystal is viewed by transmitted light at an oblique angle. Such bands may also be due to air films in incipient fractures. In some twinned crystals these color effects may not be evident. In such cases the presence of defects due to twinning may be readily tested. If a small clearly defined dot is placed on a piece of white paper and a cleavage fragment of Iceland spar placed over the dot, two dots will ordinarily appear a short distance apart, due to double refraction. If, however, the crystal is moved slowly back and forth, and the dots observed closely, additional indistinct dots may also appear in certain positions. Such a phenomenon is an indication of twinning, and crystal fragments that exhibit it are defective for optical purposes, unless the pieces which constitute the twinned form are large enough so that optical parts may be cut from them without passing beyond the plane along which such pieces are united. In searching for any such evidence of twinning, observation should not be confined to one direction, but should be made in the three principal directions through the three opposite pairs of parallel faces.

5. Inclusions of air bubbles, drops of water, streaks of clay, or other such foreign matter. Such material is worthless for optical purposes.

Defective Iceland spar has little value, although small quantities may be marketed for museum collections or to schools or colleges, for illustration of optical properties. Small amounts have been used for standardizing solutions for volumetric analysis. This requires 100 per cent pure material, which must compete with calcium carbonate from other sources. Total usage probably does not exceed a few hundred pounds annually.

Occurrence and Distribution. The finest quality of Iceland spar has been found only in calcareous veins associated with igneous rocks. A hydrothermal origin or deposition from hot springs in the last stages of igneous activity is suspected. Veins of calcite of secondary origin are of common occurrence in most limestone areas. The calcite commonly is white and opaque and worthless for optical use. A little transparent material has been found but not enough to be significant commercially.

Iceland. Transparent calcite was discovered in Iceland prior to 1650 and became widely known, hence the name "Iceland spar." Some production was

started around 1850 and eventually the deposit passed into the hands of the government. The finest material was found in mud-filled cavities in basaltic flows. The bulk of production was derived from one large pit located near Helgustadir not far from Eskifjörður. No systematic mining method was followed, and depletion of high-grade material resulted in intermittent operation and final cessation of activity so that the area is now largely of historic interest only.

Other Countries. Small and erratic production has been recorded from South Africa, Spain, Argentina, Italy, Russia, and Canada. Apparently, such output as has been recorded has been the result of sporadic discoveries, and sustained production is impossible.

Mexico. The production of Iceland spar in Mexico was begun in 1937 and by 1944 was making a substantial contribution to the soaring demands created by military use.^{4,5} Occurrences are known near Cumpas, Sonora, and in the Creel region of Chihuahua. The mineral is found only near the younger volcanic rocks. The best material occurs in vugs, sometimes loose from the enclosing walls. Float served as a useful aid in prospecting. When veins were located they were worked by hand labor with great care, explosives not being used in the neighborhood of crystals of possible optical quality. Two to three tons of mine-selected material would supply from 120 to 400 lb of acceptable optical grade after trimming and inspection. Much of the production was used for military purposes.

United States. Montana. A deposit from which considerable spar has been obtained is situated about 11 miles southwest of Greycliff, which is on the main line of the Northern Pacific Railroad about 71 miles west of Billings. Another deposit occurs about a mile further in a southwesterly direction, and about 10 miles west of Greycliff and 4 miles from Big Timber is still another deposit.

The spar occurs in two parallel vertical veins striking northwest and southeast. One is about 7 and the other 5 ft in width, and they evidently extend for several miles, maintaining their width and direction with remarkable constancy. The veins probably extend to a depth of at least several hundred feet, and there is evidently a very large supply of calcite in reserve. Most of the material is opaque white and has been used for the manufacture of chicken grit. Cavities contain some superior material from which optical spar has been recovered. War demands resulted in a renewed activity of production in this area and around Clyde Park. Most of the spar mined during the war came from this area. The calcite is resistant to weathering and crops out prominently from the surrounding rocks and soil and is conspicuous due to its white color. Suitable crystals are found only in vugs, at times loose in the mud collected at the bottom of the openings. The largest crystal found weighed 300 lb and supplied 30 lb of acceptable spar. Prospecting was done by bulldozing the surface, sinking small shafts, and drifting from the bottom. The small veins were found to be as productive of high-grade material as the large ones. All mineral suspected to be of suitable grade was taken to the surface and examined over light for flaws. The crystals were rested on bags of sand and trimmed with great care, using small hammers and chisels. A window cut on one side of a crystal permitted examination so that

fractured, twinned, or milky calcite could be rejected. Crystals chosen for retention were cleaned in a bath of dilute acid and shipped east for final selection. Some material was purchased from small local producers for \$7.50 per pound.

Other States. California. Iceland spar has been found near Cedarville, Modoc County, Calif. The calcite occurs in veins in a country rock reported to be basalt. Cavities in the veins have produced some high-grade material. It was found in vugs surrounded by loose earthy material. This deposit was known in 1920. Production in subsequent years as far as known has not been large.

New Mexico. A deposit from which some excellent material was recovered was found in the Copper Mountain mining district, Taos County, in 1931. There was little development until 1939. A conical pit was developed in which calcite, apparently of hydrothermal origin, was found surrounded by mud and earthy matter. Sustained production is not reported. Small quantities of Iceland spar have been reported in Nevada, but production is not of record.

Utilization. The Nicol prism and its use in the microscope and polariscope is the most common use. During the war the demand for Iceland spar for range-finder prisms and other uses created a tonnage market in contrast with the pre-war years, when the annual demand could be satisfied with quantities varying from 1,000 to 2,000 lb. It has been stated⁶ that in the large-consuming military uses, material with some color and trifling inclusions could be tolerated that would not qualify for first-grade optical use in other instruments. The development of "polaroid" (dyed quinine salts oriented on a sheet of plastic) has permitted the use of polarized light for many new purposes. It is used in eyeglasses and for windows in trains, planes, and autos to remove a portion of the light, thereby eliminating glare. Iceland spar is an excellent example of a rare form of one of the commonest of minerals. Advances in research in crystal chemistry suggest the possibility that in the future crystals may be grown in the laboratory equal to the best of natural production.

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CARBON DIOXIDE

The growing importance of carbon dioxide as an industrial commodity has resulted in an increased interest in its properties and its natural occurrence. The gas is manufactured for commercial purposes in large volumes. The manufacturing units are located in or near the markets, which in most cases are remote from the areas in which natural carbon dioxide may be recovered. The use of the natural gas, therefore, is not developed to the extent that might be anticipated.

Physical Properties. Carbon dioxide is a heavy gas, 1.52 times as heavy as air. It tends to accumulate at low points and may form a serious industrial hazard, since it is tasteless, odorless, and not easily detected. It is soluble in water, and solubility increases as the temperature drops. Under pressure of around 650 psi it can be liquefied. Solid carbon dioxide, dry ice, has a temperature of -78.5°C . The solid material passes over to the vapor phase with no intermediate liquid state.

Occurrence. Carbon dioxide is liberated in the atmosphere from the combustion of fuels; decay of plant and animal life; release from volcanoes, springs, and gas wells; industrial processes breaking down carbonates; and exhalation from living organisms. Doubtless, the gas would accumulate in considerable percentages if it were not for the remarkable role it plays in living processes. By the process of photosynthesis carbon dioxide is absorbed from the air by plants, with storage of carbon in their tissues and liberation of oxygen. In northern climates when deciduous trees are bare of leaves in winter the accumulation of carbon dioxide would be expected to increase in the atmosphere. Apparently it does not, due to increased solubility in water at lower temperatures.

The carbonate rocks are reservoirs of carbon dioxide of unknown but almost limitless extent. Calcite, CaCO_3 , contains 44 per cent by weight of carbon dioxide, and this mineral is the principal constituent of limestones of various types existing in billions of tons. The removal of carbon dioxide from the waters containing lime-secreting organisms is a geologic process of primary magnitude. A cubic mile of limestone, a trifling dimension in areas of sedimentary rocks, contains 4,483,876,076 tons of carbon dioxide, allowing 13 cu ft to the ton and a rock with a 90 per cent calcium carbonate content.

The drilling of oil wells disclosed the presence of carbon dioxide trapped in rock structures under high pressure.⁶ The total amount available from such sources is large. Much of it has been wasted due to difficulties of collection and transportation and distance from the market. Mexico was an early and well-known producer from this source, as well as Colorado, New Mexico, Utah, and California. Miller⁴ reports that in 1927 a well located in Jackson County, Colo., was brought in with a daily capacity of 3,000 tons. The production of natural gas is frequently accompanied by carbon dioxide, at times in large amounts.

Production. Carbon dioxide has been produced commercially in many ways. It has been recovered from natural springs and wells, as a by-product in brewing operations, by acid and thermal decomposition of carbonates, and by the combustion of coke and other fuels. Gas of high purity is desired for most purposes.

The manufactured gases must be scrubbed, and impurities removed by absorption. A gas of high purity is prepared by passing the scrubbed carbon dioxide through a solution of sodium or potassium carbonate. This is converted to bicarbonate, which when heated breaks down to carbon dioxide and the normal carbonate, which can be used again. The gas is removed and liquefied or used locally. Gas recovered from natural wells is cleaned by passage through absorption towers and then liquefied by multiple-stage compression. The liquid is sprayed through nozzles to produce a solidified gas. Gas not solidifying is used to cool the incoming liquid and then is returned to the compressors. The solid carbon dioxide is compressed to blocks for shipment and stored with careful insulation.

Utilization. New uses are continually being found. The most important are the carbonation of beverages and refrigeration of perishable products. Liquid carbon dioxide is commonly used in the preparation of soft drinks. This is transported in steel containers to the bottling plants for conversion to gas and introduction in the bottle. Solid material is extensively employed in the protection of ice cream and in the refrigeration of trucks and cars used to transport perishable commodities. It is employed as a chilling agent in many industrial operations, as an inflator of life rafts, fire extinguisher, agent for the manufacture of cellular structures, raw material for the preparation of soda ash and other carbonates, explosive in coal mining, and as an aid to cause precipitation and induce rainfall. Direct application of the gas to the soil to accelerate plant growth has been studied for years. In 1948 consumption of liquefied gas was reported at 244,184,000 lb, while use of the solid amounted to 694,926,000 lb. Liquefied gas in cylinders sells for about 6 cents per pound.

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CEMENTS AND CEMENT MATERIALS

The subject of cements and cement materials has become so complex and the literature concerning the subject so extensive that it is not expedient to present more than a brief outline. The selected bibliography at the end of the discussion contains the most useful of modern references by which further investigation may be pursued. The various types of cement are discussed in the chronological order in which they have been developed.

Pozzuolana Cement. This cement was manufactured over 2,000 years ago and was named for the town of Pozzuoli, Italy, where the most important raw material, volcanic ash, was extensively quarried. This material was ground to a fine powder and mixed with quicklime. The addition of water to the mixture initiated chemical reactions, resulting in the formation of some calcium silicates. The presence of these silicates, and probably others, caused the cement to set to a hard mass. It was used extensively by Roman engineers in construction work, and present-day examination of the ancient material shows it to be in good condition. A similar material has been produced in the United States by grinding blast-furnace slag with lime. In addition, cements have been made by grinding blast-furnace slag with portland-cement clinker, and slag is substituted in part for limestone in the production of standard portland cement. The production of pozzuolana cement is of increasing interest in the cement industry of today although it is improbable that modern industry owes any part of its development to this material.

Natural Cements. It was recognized in England in the eighteenth century that certain limestones containing clay and silica could be calcined and the product would exhibit true hydraulic properties, that is, after grinding to a fine powder it would set after the addition of water. These limestones were called hydraulic limes. Further investigation showed that mixtures of other varieties of limestone with clay and sand would produce a similar result. This led to the establishment of a natural cement industry, the direct progenitor of modern portland cement. Natural cements were produced first in the United States in 1818 in central New York. Their employment in the masonry of the locks of the Erie Canal established their usefulness. Production spread to other states and by 1899 amounted to 9,868,179 barrels. Subsequent decline has reduced the annual output to a relatively small figure. Rosendale, Ulster County, N. Y., was a leading producer, and this type of cement became known as "Rosendale," regardless of the point of production. Present output is largely utilized for masonry or brickwork, where its plasticity is useful. The cement barrel, the unit of production and sales, is equivalent to 376 lb net. This unit is believed to have originated in the barrels of cement imported from Europe that contained this quantity.

Portland cement owes its origin to Joseph Aspdin, of Leeds, England, who applied for a patent on Dec. 15, 1824. His process employed essentially the same materials as those used for the manufacture of natural cement, but differed in one significant detail. Calcination was carried to a much higher temperature.

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The name "portland" was derived from the resemblance of the set material to portland stone, one of the best known and most widely used limestones employed in construction in the British Isles. The first portland cement produced in America appeared in the Lehigh Valley of Pennsylvania in 1875. The superiority of this material over other cements led to their displacement.

Raw Materials in the Portland-cement Industry. The cement rock of the Lehigh Valley is an impure high-calcium limestone. The impurities, clay and silica, can hardly be considered impurities when the rock is used for cement manufacture, since they furnish the alumina and silica necessary for the formation of the desired silicates and aluminates. It was discovered soon that other limestones could be used and that the silica and alumina could be obtained by the addition of clay or shale. This led to a wide geographic dispersal of the industry, and portland cement is now made in 34 states. Limestone or cement rock is the largest single tonnage item concerned in the industry. The location of proper material therefore controls the location of the cement mill. Other materials, including marl, shells, alkali waste, and blast-furnace slag, may be used as a source of lime. Portland cement must conform with the specifications established by the National Bureau of Standards and the American Society for Testing Materials (ASTM). These specifications state that the magnesia (MgO) in cement must not exceed 5 per cent. Limestones possessing a sufficiently low magnesia content to produce a qualifying cement are not common, and billions of tons of limestone, otherwise suitable, are excluded from the industry. The consumption of raw material as reported by the U.S. Bureau of Mines is shown in Table 1. In 1948 the production of a barrel of cement weighing 376 lb required 654 lb of raw materials.

TABLE 1. RAW MATERIALS USED IN PRODUCING PORTLAND CEMENT IN THE UNITED STATES, 1946 TO 1948

Raw material	1946	1947	1948
Cement rock, short tons.....	10,781,078	11,728,062	13,046,856
Limestone, ^a short tons.....	34,579,673	40,034,322	43,489,837
Marl, short tons.....	860,798	563,148	601,716
Clay and shale, ^b short tons.....	4,845,224	5,373,591	6,440,584
Blast-furnace slag, short tons.....	706,986	864,617	896,474
Gypsum, short tons.....	1,157,324	1,445,622	1,507,876
Sand and sandstone, ^c short tons.....	460,910	821,017	723,769
Iron materials, ^d short tons.....	218,634	257,048	318,106
Miscellaneous, ^e short tons.....	144,139	147,056	133,716
Total, short tons.....	53,754,766	61,234,483	67,158,934
Average total weight required per bbl (376 lb) of finished cement, lb.....	655	657	654

^a Includes oystershells.

^b Includes bentonite, diatomaceous shale, fuller's earth, and other clays.

^c Includes silica and quartz.

^d Includes iron ore, pyrite cinders and ore, and mill scale.

^e Includes diatomite, fluorspar, pumicite, flue dust, pitch, red mud and rock, hydrated lime, tufa, cinders, calcium chloride, sludge, grinding aids, and air-entraining compound.

CEMENTS AND CEMENT MATERIALS

In 1945, limestone and clay or shale accounted for 71.4 per cent of the total production of portland cement; cement rock and pure limestone, 19.8 per cent; blast-furnace slag and limestone, 6.8 per cent; and marl and clay, 2.0 per cent.

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, is added to the clinker just before final grinding to finished cement. The amount added is controlled by the official specifications, which state that the sulfur trioxide in ordinary finished cement must not exceed 2 per cent. From 9 to 12 lb of gypsum per barrel of cement are generally added. Gypsum plays a very important role in that it controls the set of the cement, prevents quickset, and ensures the delivery of a uniform product. Gypsum-anhydrites mixtures are also used.

Fuels. The selection of fuel is based on economic considerations. Solid, liquid, and gaseous fuels are employed. The consumption of fuel as reported by the U.S. Bureau of Mines is displayed in Table 2.

TABLE 2. PORTLAND CEMENT PRODUCED IN THE UNITED STATES, 1946

Fuel	Finished cement produced			Fuel consumed ^a		
	No. of plants	Bbl of 376 lb	Per cent of total	Coal, short tons	Oil, bbl of 42 gal	Natural gas, M cu ft
Coal.....	91	92,469,773 ^b	56.3	5,746,785		
Oil.....	13	12,615,568 ^b	7.7	.....	2,583,183	
Natural gas.....	12	11,762,138 ^b	7.2	.....	.....	17,397,628
Coal and oil.....	10	14,566,471	8.9	883,015	554,919	
Coal and natural gas.....	13	13,281,081	8.1	359,160	.....	16,025,258 ^c
Oil and natural gas.....	7	13,324,422	8.1	.....	764,048	15,034,902
Coal, oil, and natural gas...	6	6,044,735	3.7	19,770	84,271	9,546,321
	152	164,064,188	100.0	7,008,730 ^d	3,986,421	58,004,109

^a Figures compiled from monthly estimates of the producers.

^b Average consumption of fuel per barrel of cement produced was as follows: 1945—coal, 126.9 lb; oil, 0.2041 bbl; natural gas, 1,421 cu ft. 1946—coal, 124.3 lb; oil, 0.2048 bbl; natural gas, 1,479 cu ft.

Includes 824,665 thousand cu ft of by-product gas.

Includes 12,004 tons of anthracite and 4,193,220 tons of bituminous coal.

^c Includes 2,090,100 thousand cu ft of by-product gas.

^d Includes 19,120 tons of anthracite and 6,989,610 tons of bituminous coal.

For detailed reports of studies of fuel efficiency, see Yaworski, *et al.*²⁴

Production and Processing. Cement is such a low-priced commodity and is sold in such a highly competitive market that it must be produced with the greatest economy and with the utilization of the most modern and efficient methods of rock breaking, transportation, grinding, and calcination. Small units are not efficient, and the minimum mill that would be considered today would not be likely to have an annual capacity of under 1,000,000 barrels. Since such a mill would represent an investment of approximately \$6.00 per annual barrel under present conditions, it is apparent that the capital requirements are substantial. The rock is recovered from large quarries; or the marl or shell is dredged from excavations; crushed; proportioned with clay, shale, or other materials under exact chemical control; and then ground to proper size for kiln feed. Wet and dry grinding are both employed. The rotary kiln, introduced in 1886, is the

largest single unit of moving machinery in industrial use. The kiln, a cylindrical steel tube up to 500 ft in length and lined with the necessary refractories, is rotated at a very low rpm and placed at a slight incline so that the charge moves gradually to the lowest end, where the burning equipment is placed. As the kiln feed advances it is heated so that moisture is expelled, the carbonates are broken down to oxides, and finally in the hot zone the silicates and aluminates are formed to which portland cement owes its effectiveness. Incipient fusion is attained, producing clinker. This clinker is stable and may be stored outdoors without harm. However, after it is mixed with gypsum and ground to a fine powder its hydraulic properties appear, and from this time forward it must be protected from moisture in all forms with the greatest care.

Data relative to the magnitude of the industry in the United States according to the U.S. Bureau of Mines are shown Table 3.

TABLE 3. PRODUCTION AND PRICE OF PORTLAND CEMENT
(Capacity utilized)

Year	Bbl	Average factory price per bbl	Per cent of capacity utilized
1938	105,357,000	\$1.45	45.5
1939	122,259,154	1.47	41.2
1940	130,216,511	1.46	47.7
1941	164,030,559	1.47	51.2
1942	182,781,184	1.53	66.3
1943	133,423,788	1.57	73.5
1944	90,905,696	1.59	55.0
1945	102,804,884	1.63	37.8
1946	163,805,000	1.72	42.5
1947	186,519,347	1.90	74.9
1948	205,448,263	2.18	80.8

The Flotation Process. The flotation process was originally applied to the beneficiation of metallic ores. It was first used by the Valley Forge Cement Co. of West Conshohocken, Pa., to improve the quality of limestone. It is now in extensive use in many countries. Silica and silicates present in limestone in excessive amounts may be removed by its use. Limestone deposits, otherwise not suitable for cement manufacture, are thereby made useful. Cement of the highest quality may be produced from materials previously considered inferior or worthless. Installation of flotation cells in a wet-process mill does not introduce any special difficulties, and the additional expense of initial cost and operating expense are compensated by savings in fuel and grinding costs.

Special Cements. Increased specialization has been conspicuous in the portland-cement industry for the past two decades. Cements are produced with low heat of hydration, high resistance to sulfate attack, high early strength, exceptional plasticity, white color, and water resistance. Air-entraining cements are of growing importance. Such cements contain several per cent of voids induced by the addition of air-entraining compounds. Such compounds may be applied

to any type of cement. The cement so treated produces a concrete exhibiting superior resistance to scaling, due to alternate freezing and thawing, and also improved working qualities.

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CHALK AND WHITING

Definition. *True chalk* (also known as "cliffstone") is a soft, compact, fine-grained, light-colored type of limestone, composed essentially of the calcareous remains of small marine organisms and shells. When pure it consists entirely of calcium carbonate, CaCO_3 , but it often contains impurities, such as silica (chiefly in the form of flint), clay, iron compounds, and so on.

Whiting is finely pulverized chalk, used for many purposes. As noted below, whiting substitutes (often sold as whiting) are made from a variety of calcareous materials.

French chalk and some varieties of *tailors' chalk* are not chalks at all, but are compact forms of talc.

Red chalk, *billiard chalk*, and some types of *tailor's chalk* may be compact earthy hematite, colored clay, colored plaster of paris, or sometimes (but not usually) true chalk colored and compressed with a binder.

Black chalk is a soft carbonaceous or graphitic schist or clay.

Blackboard chalk may be either plaster of paris, true chalk, or even talc.

True chalk was once considered to be amorphous and its putty-making properties were attributed to that factor, but microscopic studies have shown that, in large part, it is cryptocrystalline.

Chalk Substitutes. Although there is an abundance of true chalk in the United States, very little of it is white enough or pure enough to form an acceptable substitute for European chalk for the more important uses. Prior to the First World War most of the needs for chalk for paint and putty whiting were supplied by imports. When foreign supplies were cut off by war domestic limestones and marbles were ground to make whiting substitutes, the term "whiting" being then applied exclusively to the product made from true chalk. At first these sub-

stitutes were not very satisfactory because they were lacking in plasticity and resulted in a "short" putty. Eventually, by selection of limestones and by finer grinding, fairly acceptable putty whiting substitutes were made, and these products were also accepted by the paint and rubber trades. After the First World War imports of chalk were resumed, but the substitutes had gained a foothold in the paint and rubber industries and production continued. Then it was found that by blending chalk whiting with some of the more plastic finely ground limestones their quality could be improved to fit them for making good putty. Gradually the term "substitute" was almost wholly dropped. The use of precipitated calcium carbonates as fillers in the paint, rubber, and paper industries greatly increased, as did the use of the finest ground limestones and marbles. Today the use of true chalk whiting is of minor importance except in putty, and here it is largely used as a blend with ground limestone.

Whiting substitutes are now made from limestone, marble, dolomite, white marl, vein calcite, ground oystershells, and precipitated calcium carbonates, both primary and by-product.

Distribution. True chalk deposits of large size occur in Alabama, Arkansas, Kansas, Mississippi, Nebraska, Oklahoma, South Dakota, Texas, and Wyoming. Of these deposits Wilson and Skinner say, "These have the fineness of grain, similar paleontological origin, and even stronger putty plasticity than the European chalks, but the domestic samples included in this study did not equal the European in color and purity. The average oil absorption was higher than that of the European chalk, although several individual samples were within the commercial limits." Carbon and iron oxide darken the whiting and prevent its use where a light cream or white is necessary."²² Some of this chalk is used as ordinary limestone for making portland cement.

Ground limestone and dolomite, used for limestone whiting, is produced in many states, including Alabama, California, Georgia, Illinois, Michigan, Missouri, Nebraska, New York, Pennsylvania, Vermont, and probably several other states.

In England, France, Belgium, Denmark, and other European countries very pure true chalk occurs in large deposits in many localities. In several of these countries it is produced in large quantities and is used chiefly as ordinary high-grade limestone in making lime, portland, and other calcareous cements for agricultural purposes and so on. Much smaller quantities are ground and sold as whiting or shipped in the crude state to the United States and other countries for whiting manufacture.

Production and Consumption. Due to the fact that calcium and calcium-magnesium carbonates, both natural and precipitated, are made for filler use from so many different types of raw material and are used for so many different purposes, it is difficult to get a very clear statistical picture of either production or consumption. The true chalk picture is indicated by imports. In 1913 crude true chalk imports totaled 169,130 short tons, valued at \$120,049; precipitated chalk nearly 7,300 tons; and whiting nearly 1,800 tons. By 1946 these imports had shrunk to 2,190 tons of precipitated chalk valued at \$85,506 and 5,381 tons of whiting valued at \$67,437.

In 1946 sales of ground limestone for use as whiting totaled 405,380 short tons

valued at \$3,523,025. This was 50 to 60 thousand tons more than sales in 1944 and 1945. In addition, nearly 1¼ million tons of more coarsely ground limestone was sold for asphalt, fertilizer, and other filler uses. Statistics are not available for the production of precipitated calcium and calcium-magnesium carbonates, but they were very large.

Preparation of Whiting. Both chalk and pure limestone are so soft that grinding problems are relatively simple. True chalks develop proper working plasticity, by either dry or wet grinding, at particle sizes considerably coarser than with limestone or marble. Some hard limestones develop good plasticity with prolonged grinding to a very fine particle size, but this also increases the oil absorption. For putty the extreme fineness of precipitated whittings causes them to become sticky and unworkable when mixed with linseed oil, but this stickiness may be lessened by the addition of coarser particles. For rubber filler and many other filler uses the tendency for many years has been toward finer and finer grinding. Thus, the choice of grinding methods depends both on the nature of the raw material and the intended uses.

Dry grinding is done with impact pulverizers, roller mills, ball mills, and pebble mills in closed circuit with some form of air separation. Finenesses down to 99.8 per cent through 325 mesh ($43\ \mu$) are obtained by these more common dry-grinding methods. Still finer dry grinding is done with fluid-energy mills of the micronizer type, which are reported to reach particle sizes down to $1\ \mu$ and average products at $10\ \mu$ and under. Wet grinding is done in continuous ball, pebble, and Hardinge conical mills in closed circuit with various types of classifiers. Extremely fine particle sizes are attained by grinding in Hardinge conical mills in closed circuit with Bird continuous centrifuges. Wet grinding is considerably more costly than dry grinding since the finished slurry has to be thickened, filtered, and dried.

Precipitated calcium carbonate¹⁴ may be made as a primary product (1) by passing carbon dioxide gas through a suspension of calcium hydroxide, or (2) by reacting calcium chloride in solution with sodium carbonate. It is made as a by-product (1) in the making of caustic soda from lime and soda ash, $\text{CaO} + \text{H}_2\text{O} + \text{Na}_2\text{CO}_3 = 2\text{NaOH} + \text{CaCO}_3$; and (2) in making precipitated basic magnesium carbonate from dolomite. In making precipitated calcium carbonate as a primary product particle size and shape can be very accurately controlled to alter the physical properties of the product. These properties may also be changed by surface treatments of the particles with stearates and fatty acids.

Specifications and Tests. Except for chemical uses such as in the ceramic industries, chemical composition is of little guide to suitability for any use. Physical properties are of vital importance in nearly all uses, but chemical properties such as alkalinity are important in some applications. Because of the wide variations in type, raw material, and methods of processing, products in this group vary greatly in composition and in physical and chemical properties. For most uses each consumer sets up his own standards for each product. Products range in particle size from coarsely ground agricultural limestone and asphalt filler through the dry-ground paint fillers to the low-micron-size precipitated carbonates used for paper coating.

CHALK AND WHITING

For ceramic whiting two types are recognized, one low in magnesia and one with an appreciable magnesia content. Class 1 whiting must contain a minimum of 96 per cent CaCO_3 and maxima of 1.0 per cent MgCO_3 , 0.25 per cent Fe_2O_3 , 2.0 per cent SiO_2 , and 0.1 per cent SO_3 . Class 2 whiting may contain 8 per cent MgCO_3 .

In paint, fineness, freedom from grit, whiteness, oil absorption, and particle shape are important.

In putty, the controlling properties are plasticity, color, oil absorption, hardening ability, and aging qualities.

Wilson and Skinner²² discuss in detail the testing of whiting for various uses.

Prices. Precipitated chalk, cosmetic and dental grade, was quoted in 1950 at prices varying from $2\frac{7}{8}$ to 5 cents per pound in carloads fob works. Papermaker's chalk was quoted at \$32.50 to \$40.00 per ton, and rubbermaker's at \$32 per ton, all in bags and fob works in carload lots. Dry-ground limestone, 325 mesh, was quoted at prices from \$11 to \$19 per ton; and wet-ground, air-floated, 99 per cent through 325 mesh, from \$16 to \$30 per ton, all in bags, carloads, fob works. Putty grade was \$13 per ton.

Utilization. The chief use for true chalk (except for such bulk uses as for portland cement) is for making putty. Putty is essentially a mixture of whiting and linseed oil, but manufacturers make several types and grades for different types of use, with mixtures of chalk and limestone whittings, admixtures of white lead, and sometimes adulterants such as china clay and silica.

The largest uses for ground limestone whiting are in paint and rubber, but other uses are in linoleum, oilcloth, window-shade cloth, insulated wire and cable, white shoe dressings, as a mild abrasive, in ceramic glazes and enamels, and for many minor uses.

Chemically precipitated whittings are used in paper filling and coating,¹⁴ in dentrifices, pharmaceuticals, and toilet preparations, as a rubber pigment, in paints and enamels, and as a chemical reagent.

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CHROMITE*

Composition. Chromite, an oxide of chromium and iron, FeCr_2O_4 or $(\text{FeCr})(\text{Cr,Fe})\text{O}_2$. It may contain magnesium and aluminum. Pure chromite contains, theoretically, 68 per cent chromic oxide (Cr_2O_3) and 32 per cent ferrous oxide (FeO). Composition of common chromite ore may be represented as $(\text{FeMg})\text{O}(\text{CrAl})_2\text{O}_3$ plus serpentine. Commercial chromite of metallurgical or chemical grade contains from 44 to 50.5 per cent Cr_2O_3 . Refractory chromite commonly runs from 34 to 36 per cent. Research has shown that satisfactory refractories can be produced from material with a Cr_2O_3 content as low as 28 per cent. Com-

* Chromite is really a metallic mineral and is usually so considered, but in normal times about one-half of the chromite produced is consumed for nonmetallic mineral purposes (for refractories, chemicals, etc.) instead of as a source of a metal. For this reason it has seemed necessary to treat chromite briefly in this work.

CHROMITE

mercial chromite usually contains 40 to 50 per cent Cr_2O_3 or more, with alumina, magnesia silica, and lime as the chief impurities.

General Description. Chromite (also called chrome iron and chromic iron ore) is usually found as a massive black mineral resembling magnetite or in finely granular masses or as disseminated grains. It often occurs mixed with serpentine.

Physical Properties. *Hardness*, 5.5. *Specific gravity*, 4.3 to 4.6. *Melting point*, 2180°C . *Index of refraction*, 2.16. *Color*, iron black to brownish black. *Streak*, generally a typical coffee brown, a valuable means of identification when used as a field test. *Luster*, submetallic to metallic. *Cleavage*, indistinct octahedral. *Fracture*, uneven to conchoidal. *Transparency*, opaque. *Tenacity*, brittle. Sometimes slightly magnetic.

Occurrence and Distribution. Chromite is a common constituent of most basic rocks, particularly peridotite, a rock consisting largely of pyroxene and olivine. This rock alters readily to serpentine. The association of chromite with serpentine is therefore common. The distribution of chromite throughout its host rock frequently is irregular and not connected with any observable control. The determination of the ore content of a deposit, the reserves for the future, or the value of the deposit generally cannot be determined with satisfactory accuracy.

TABLE 1. CHROMITE PRODUCTION (SHIPMENTS) IN THE UNITED STATES, 1944 TO 1948 BY STATES, SHORT TONS, AND NUMBER OF PRODUCERS IN 1948

State	1944	1945	1946	1947	1948	
					No. of producers	Short tons
Alaska.....	1,845					
California.....	34,715	9,607	*4,107	948	3	274
Montana.....	1,251					
Oregon.....	7,818	4,366	.....	...	2	3,345
Total.....	45,629	13,973	4,107	948	5	3,619

* California and Oregon production combined. Bureau of Mines not at liberty to publish separate state totals for 1946.

Chromite in the United States. Chromite was first mined in the United States in a serpentine belt extending from Lancaster County, Pa., nearly to Baltimore, Md. Production originated in placer deposits found in stream beds and later was transferred to underground operations. These deposits supplied most of the world's production from 1828 to 1850. The ore was shipped from Baltimore to Europe, where most of it was converted to chromates and dichromates for chemical use. After 1850 a rising output from Turkish Asia Minor began to dominate European markets. The Wood mine located in Pennsylvania was at one time the largest producer in the world. It was in operation from 1828 to 1882, except from 1868 to 1873, when it was flooded. Exhaustion of the ores resulted in the center of chromite production migrating to California. The total

production from the Pennsylvania-Maryland district is believed to have exceeded 200,000 tons of high-grade ore. The Wood mine was dewatered in 1937 to its lowest level, about 720 ft, but examination failed to disclose ore of industrial interest. Domestic resources are inadequate to satisfy the rapidly increasing demands for the mineral, and foreign imports have been a necessity for years. Domestic supply in 1946 was restricted to California and Oregon, as shown in Table 1.

The inadequacy of domestic supply for industrial consumption is shown in Table 2.

TABLE 2. TOTAL SUPPLY, IMPORTS FOR CONSUMPTION, DOMESTIC PRODUCTION, AND CONSUMPTION OF CHROMITE, 1942 TO 1946, SHORT TONS

	1942	1943	1944	1945	1946
Total supply.....	1,094,483	1,088,696	894,019	928,738	761,498
Imports for consumption....	981,607	928,576	848,390	914,765	757,391
Domestic production.....	112,876	160,120	45,629	13,973	4,107
Consumption by industry.....	981,952	964,600	848,449	808,120	734,759

Under the impetus of wartime demands, high prices, and government aid, chromite production in the United States exhibited marked expansion in the First and Second World Wars. In each case the cessation of hostilities was followed by a drastic reduction in output as imports of foreign origin resumed their normal status. This is shown in Table 3.

Experience of the war years has demonstrated that supplies of chromite in the United States are few in number, low in ore content, and with few exceptions unable to compete economically with material of foreign origin.

The origin of chromite imported in the United States is shown in Table 4.

Foreign Countries. Disturbance of normal commerce incident to the war has altered the productive position of the world's leading producers. It is possible at the present time that Russia

TABLE 3. CHROMITE SHIPPED FROM MINES IN THE UNITED STATES, 1913 TO 1921 AND 1938 TO 1946

Year	Short tons	Year	Short tons
1913	286	1938	909
1914	662	1939	4,048
1915	3,675	1940	2,982
1916	52,680	1941	14,259
1917	48,973	1942	112,876
1918	92,322	1943	160,120
1919	5,688	1944	45,629
1920	2,802	1945	13,973
1921	316	1946	4,107

is the leading producer with her high-grade deposits on the east side of the Urals around Sverdlovsk. Rhodesia, Turkey, South Africa, Cuba, the Philippines, India, Greece, and New Caledonia tend to follow in approximately that order.

Utilization. Fifty per cent of the chromite used in the United States is consumed in the metallurgical industries. This use has increased rapidly due to the popularity of nickel-chrome alloys and stainless steels with high chrome content. The use of chrome plate on the brightwork of the automobile has created a sub-

CHROMITE

stantial demand. Chrome brick as a refractory was first employed by the steel industry around 1896. Its chemical stability recommends its use. Relatively low-grade chrome ores can be used for this purpose. A large number of chromium compounds are prepared for chemical use. Among them, sodium and potassium chromate and dichromate are the most common.

TABLE 4. CHROMITE IMPORTS, 1946

Area	Short tons	
	Gross weight	Cr ₂ O ₃ content
Canada.....	8,607	4,090
Cuba.....	204,268	73,129
U.S.S.R.....	98,952	53,391
India.....	17,268	8,500
Philippines.....	30,465	10,469
Turkey.....	9,015	4,328
Sierra Leone.....	32,912	14,164
Southern Rhodesia.....	99,557	47,228
Union of South Africa.....	235,340	105,831
New Caledonia.....	21,007	11,326
Total.....	757,391	332,456
Total.....	\$11,459,121	

NOTE: In 1948 imports amounted to 1,542,125 tons. Twenty-five per cent of this tonnage came from the U.S.S.R.

Specifications and Prices. *Metallurgical grade:* minimum Cr₂O₃, 49 per cent. Chromium to iron ratio, 3:1 or more. Ore to be in lumps. (During the war material with a ratio of 2.5:1 in the form of concentrates or fines was accepted to a limited degree.) *Refractory grade:* specifications vary with the customer, based on performance. Lump ore is preferred with not over 5 per cent SiO₂, and at least 50 per cent of combined Al₂O₃ and Cr₂O₃. *Chemical grade:* concentrates and fines preferred. The chrome content should be high and SiO₂ low. Specifications vary with the customer. In 1950 chromite was quoted per long ton, fob eastern seaports, as follows: Indian and Rhodesian, 48 per cent Cr₂O₃, 3:1 ratio, \$35 to \$36; 48 per cent Cr₂O₃, 2.8:1 ratio, \$34 to \$35; South African, Transvaal, 48 per cent Cr₂O₃, no ratio, \$26; 44 per cent Cr₂O₃, no ratio, \$17 to \$18; Turkish, 48 per cent Cr₂O₃, 3:1, \$37 to \$38.

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CLAYS AND CLAY PRODUCTS

Clay is a very common substance which occurs in a great many types and varieties, with differing physical and chemical properties, and which is used, both in its natural state and after burning, to make a wide range of products. It is produced and used in nearly every country of the world, by many methods and for many purposes. The literature of clay and its products is extensive, but it is filled with many inadequate discussions and conflicting opinions. Furthermore, much of the literature is unsatisfactory, for other reasons.

A proper exposition of the economic and commercial phases of clay, in all its forms and for all its uses, would require many volumes. It is obvious, therefore, that the treatment here given can consist of but a brief outline and must include many generalized statements. Even a generally acceptable definition of clay cannot be given, for authorities still have divergent views on this subject. In the following discussion, information is used from many, but generally accredited, sources.

Definition of Clay. Clay is a natural mineral substance which, in a finely divided state—either natural or produced by grinding—when mixed with the proper amount of water, is plastic, that is, it can be molded and will retain its molded form upon drying. (A few clays, such as kaolin and flint clay, are plastic to only a slight degree.) When heated to a moderate temperature (a dull-red heat in many cases, but the range is considerable), the particles lose their chemically combined water, soften enough partly to coalesce, and form a stony mass upon cooling. Most clays consist of a mixture of several minerals, but that which predominates, known as the "clay base" or "clay substance," corresponds

TABLE 1. ANALYSES OF CLAYS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO ₂	46.3	46.95	48.26	44.23	44.85	48.99	45.39	44.70	11.50	55.21	56.44	59.96	68.02	56.00	48.99	55.60
Al ₂ O ₃	39.8	37.24	37.64	38.92	33.15	32.11	39.19	35.90	74.03	31.18	26.60	15.76	14.92	22.50	28.90	14.80
Fe ₂ O ₃	0.40	0.40	0.46	2.31	2.04	2.34*	0.45	3.35	0.97	0.07	2.00	7.72	4.16	6.70	3.89	5.80
CaO.....	Trace	Trace	0.06	0.12	0.30	0.43	0.51	3.00	Undet.	0.18	0.47	0.60	1.48	1.20	7.10	5.70
MgO.....	Trace	Trace	Trace	Trace	0.42	0.22	0.29	0.21	Undet.	0.11	0.63	0.93	1.09	1.40	3.66	2.48
Na ₂ O.....	0.24	0.24	1.56	{0.26	{0.10	3.31	0.83	0.29	Undet.	0.23	{0.26	3.66	1.80	3.70	4.73	{1.07
K ₂ O.....	0.49	0.49	.....	{0.30	{0.66	.....	.....	.....	.....	.....	{3.20	.....	1.50	.....	.....	{3.23
TiO ₂	0.05	0.05	.....	1.21	0.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
SO ₃.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
H ₂ O+†.....	13.9	14.10	12.02	12.90	18.45	9.63	14.01	12.20	.....	.....	.....	.....	.....	.....	.....	0.15†
H ₂ O-§.....	.....	.....	.....	.....	.....	.....	.....	.....	13.20	{13.02	{7.57	{0.73	{3.55	7.00	3.31	{5.18
MnO.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	{0.23	{2.48	{7.70	{2.78	.....	.....	{4.94||
Total.....	100.0	99.47	100.00	100.25	100.00	97.03	100.67	99.65	99.70	100.23	99.65	98.06	190.60	98.50	100.58	98.09

* Ferrous oxide-FeO.

† Phosphorous pentoxide-P₂O₅.

‡ Above 100°C or chemically combined water.

§ Below 100°C; mechanical water or loss on ignition.

|| Includes CO₂.

1. Theoretical composition of pure kaolinite.

2. Washed kaolin, Harris Clay Co., Bryson, N.C., *U.S. Bur. Mines, Bull. 53*, 1913, p. 126.3. Washed kaolin, Cornwall, England; *U.S. Geol. Survey, Profess. Paper 11*, 1903, p. 39.4. "Sedimentary" kaolin, Immaculate Kaolin Co., near Langley, S.C. Analysis quoted in *U.S. Geol. Survey, Bull. 708*, 1922, p. 168.5. Ball clay (used for whiteware and electrical porcelain), near Whitlock, Tenn., Mandle Clay Mining Co. Analysis quoted in *U.S. Geol. Survey, Bull. 708*, 1922, p. 168.

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11. Stoneware clay, Steubenville, Ohio. Analysis by Ries, *op. cit.*, p. 398.12. Sewer-pipe clay, Laclede mine, St. Louis, Mo. *Geol. Survey Mo.*, Vol. 11, p. 570, 1896.13. Loess brick clay, Guthrie Center, Iowa. *Geol. Survey, Iowa*, Vol. 14, p. 541, 1904.14. Paving-brick clay. Average analysis, *Geol. Survey, Mo.*, Vol. 11, p. 456, 1896.15. Common-brick clay (glacial), West Cambridge, Mass. Analysis quoted by Ries, *op. cit.*, p. 341.16. Albany slip clay, Albany, N.Y. *Geol. Survey, Ohio*, Vol. 7, p. 105, 1893.

closely to the mineral kaolinite or to similar hydrous aluminum silicates, or to montmorillonite or illite. In addition to the hydrous aluminum silicate base, there are commonly present in varying amounts a great variety of minerals, of which some of the more usual are quartz, feldspar, the micas, limonite, calcite, gypsum, hornblende, garnet, titanite, ilmenite, soluble alkaline salts, and so on, together with organic matter and water.

Composition. Clays vary widely in mineralogical and chemical composition, but in their purest phases, as noted above, approach the composition of kaolinite or, at times, other of the type minerals such as halloysite, illite, or montmorillonite.

Far more is known now about the composition of clays and the structure of the individual minerals than a generation ago. This is due to research employing the most recent techniques, among which the X-ray, thermal analysis, and the electron microscope have been important contributors. Significant contributions have been reported in the bibliography.²³⁻³¹ Important clay minerals are listed in Table 2.

TABLE 2

Kaolinite.....	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
Halloysite.....	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 4\text{H}_2\text{O}$
Illite.....	A complex hydrous silicate of Al, Fe, Mg, and K
Montmorillonite.....	A complex hydrous silicate of Al, Mg, and Na

The composition of *kaolinite* is Al_2O_3 , 39.8 per cent; SiO_2 , 46.3 per cent; H_2O , 13.9 per cent. It ordinarily occurs as a very finely granular, very slightly plastic white clay, but rarely crystallizes in minute rhombic or six-sided, monoclinic scales or plates. *Hardness*, 1 to 2.5. *Specific gravity*, 2.6 to 2.63. *Index of refraction*, 1.561. *Melting point*, when pure, about 1850°C , but this is materially lowered by small amounts of impurities. It has a smooth or slightly soapy feel and, in common with all clays, has a characteristic odor, particularly when wet, called the "clayey odor." It is soluble in hot sulfuric acid.

The term "kaolin" is used to refer to the slightly impure commercial grades of nonplastic white clays that approach the mineral kaolinite very closely in composition. True kaolins are generally regarded as those found in residual deposits, and some authorities object to the term "sedimentary kaolin" (for such deposits as those near Langley, S.C.) as a misnomer.

The chemical composition of a clay is little indication of its physical properties or of its value, except in a general way. A chemical analysis may reveal the presence of impurities that would be harmful for many uses, but the presence of such impurities may usually be detected by inspection or by simple physical or chemical qualitative tests. However, the analysis may reveal no such impurities, and yet the clay may be later shown by ceramic tests to be unsuitable for any but the lowest grade uses.

The great variation in the composition of clays is shown in Table 1.

Halloysite is found widely spread, sometimes with kaolin. Deposits of commercial importance of this mineral are unusual and limited in size.

Illite is similar in composition to muscovite mica. Its identity and significance as a clay mineral has been emphasized by the work of Grim.²⁴

Montmorillonite occurs in shreds and thin plates. It is characteristically developed in bentonite and is discussed in the section dealing with that material.

In addition, there is a long suite of clay minerals of scientific interest but limited industrial importance. Among them might be mentioned anauxite; beidellite; nontronite; dickite, a variety of kaolin; and allophane, an amorphous mixture of varying amounts of silica, alumina, and water.

A large number of names are used to denote various types of clay. The nomenclature is complex and contains many items of local and obsolete usage, as listed by Kerr and Hamilton.⁶

Origin of Clays. Clay deposits are of two general types: residual and sedimentary; but in all cases the clay is of secondary origin, that is, it was formed by the alteration of some other rock.

Residual deposits are formed by the alteration or decomposition of a rock in place. This alteration may be of two forms, one involving chemical change resulting in the formation of clay, and the other involving simple solution of a rock containing clayey impurities and the consequent deposition of the insoluble clay. Residual clay deposits of the first type are usually formed by the chemical alteration and physical disintegration of feldspars, pegmatites, granites, and other feldspathic rocks. The alteration of pure feldspars will result in pure kaolins, and the alteration of granites will result in mixtures of kaolin, silica, and mica, together with other impurities originally in the granite.

When the calcium carbonate in a limestone high in clayey impurities is dissolved and removed by acid ground waters, the clay is left as a residual deposit. This clay, however, was formed originally by the alteration of a feldspathic rock, transported by water, and redeposited in disseminated grains in the calcareous bed that later formed the limestone.

Large surface deposits of residual clays are not to be expected where glacial or surface-water erosion has been active in geologically recent times.

Deposits of sedimentary or transported clays may have been formed (1) by steam transportation and deposition; (2) by deposition from glacial ice or glacial waters (these deposits often contain many stones, and are known as "drift" or "boulder" clays); (3) by wind transportation (deposits of very fine-grained, often calcareous, clay); and (4) by combinations of any of the other three processes. After the deposition of the bedded clays, they may have been subjected to sufficient pressure to consolidate them to some degree. These consolidated, usually laminated clays are called *shales*.

Allen⁶⁵ has mentioned that additional movements of the clay minerals after the formation of the clay may cause further changes that tend to increase the complexity of the clay.

Chemical and Physical Properties. The behavior of a clay, and therefore its value and suitability for any specific use, depends upon both its chemical and its physical properties. Its chemical properties depend upon the nature and the amount of impurities present, and its physical properties depend both upon chemical composition and upon other factors not well understood and not easily measurable.

Ries notes that "All the constituents of clay influence its behavior in one way or

another, their effect being often noticeable when only small amounts are present."¹³ Therefore the chemical composition is of great importance, but, as noted before, the chemical analysis alone is no adequate guide to the behavior of a clay. Two clays of the same appearance and chemical composition often behave entirely differently when molded and fired.

Principal Impurities. Some of the common impurities that exercise an important influence on the behavior of a clay are noted below.

Silica (SiO_2), always present either in the form of quartz or in silicates, has an important influence but is not deleterious for most uses, except in very large amounts.

Compounds of iron, such as the oxides, limonite and hematite, the carbonate, siderite, and the sulfide, pyrite, act as coloring agents and as fluxes. The color of red brick is due to iron compounds.

Lime, present as the carbonate, as a silicate (lime feldspar) or as the sulfate (gypsum), is usually considered a very injurious impurity for most uses. Ordinarily, it is permissible only in low-grade clay products.

Compounds of the alkalis (Na_2O and K_2O), nearly always present, are most powerful fluxes. Vitrification is impossible if they are absent.

Compounds of manganese are rarely present, except sometimes in brick clays, when they act as coloring agents.

Water is present in two forms: as mechanically held moisture, and as chemically combined water. Mechanical water has an important influence on drying, shrinkage, and cracking. Excessive combined water gives a high fire shrinkage and tends to cause warping and cracking.

Carbonaceous matter gives a gray or a black color to the raw clay, but it usually burns out. It may cause difficulties on burning.

Soluble salts, usually sulfates, but sometimes carbonates, are occasionally present. They are undesirable, since they may cause an efflorescence on the finished product.

Physical Properties of Unburned Clays. The most important physical properties of unburned clays intended for ceramic use are noted below.

Plasticity is one of the most essential properties of most clays. It is that property of certain substances by which the form may be changed by pressure, without rupture, the form being retained after the pressure is removed. The cause of plasticity is not known, but has been the subject of much research and controversy.

Texture or fineness of grain size exerts an important influence on physical properties, such as plasticity, shrinkage, and porosity.

Cohesion is that property which causes masses of clay to adhere after they have been brought in contact and pressure has been applied.

The amount of water required to produce maximum plasticity, or *tempering water*, has an important bearing on drying shrinkage.

Air Shrinkage or Drying Shrinkage. When clays dry, they always shrink or contract to a greater or lesser extent, and allowance must be made for this when a finished product of definite size is to be made. High drying shrinkage often causes distortion and cracking.

Tendency to Crack on Drying. This defect, if it cannot be remedied, renders a clay valueless for most purposes.

Slaking, when applied to clay, refers to the physical disintegration of clay in water. It is not a true slaking, as the term is applied to lime, for no chemical action takes place. The rate and the extent of slaking are of practical importance in the tempering of clay.

The *tensile strength of unburned clay* is important, for a clay of too low tensile strength may be too weak to stand the necessary handling after molding.

Porosity is the amount of pore space between the clay particles, expressed as a percentage of the total volume of the clay. It depends upon grain size and shape and has an important influence on the drying and burning behavior of a clay.

Behavior during and after Burning. When a clay is burned, a number of changes take place, some physical and some chemical. The temperatures at which these changes occur, the behavior of the clay during these changes, and the properties of the finished products are all important factors.

The *dehydration period* (called "water smoking" by brickmakers) is the period at the beginning of the burning process during which the moisture is driven off.

The *oxidation period* is the second period reached in burning as the temperature is increased. During this period the organic matter, sulfur, and carbon dioxide are driven off and ferrous iron is oxidized to the ferric state.

The *vitriification period* follows oxidation as temperatures are further increased. Vitriification is the result of complete destruction of the original clay texture and structure by at least partial fusion and by chemical reaction between the constituents. The temperature of vitriification and the *vitriification range*, that is, the temperature range between incipient vitriification and the point of viscosity or complete fusion to a soft, viscous mass, are factors of utmost importance. If a vitriified product must be made and the vitriification range is too short, it may be impossible to control the kiln temperature so closely that the ware will not melt and lose its shape.

The burned clay, depending upon the nature of its intended use, must be tested for some or all the following properties: the percentage of *fire shrinkage*; *tensile strength*; *porosity*; *absorption*; tendency toward *cracking*, *warping*, *blistering*, and so on; *color*; *translucency*; *hardness*; and *toughness*.

If the clay is to be used in a mixture with other ingredients, such as feldspar and silica (as in a porcelain body), its behavior may also be tested in a standard mixture.

Types of Clay. Clays have been classified upon many different bases and in many different ways. Thus, they may be classified according to their origin, their chemical or physical properties, their uses, or combinations of any or all of these. From a commercial standpoint probably the classifications by properties and uses are most important. It should be noted, however, that no classification can be perfect, for one clay may be adapted for several widely differing uses (for example, kaolin used both for chinaware and for paper filler); and the properties of clays may grade by almost imperceptible degrees from those of one class to those of another class. The following classifications are given as typical.

Classification of Clays by Uses.* Clays may be classified thus:

High-grade clays:

Whiteware clays (nonplastic and plastic):

Kaolin, porcelain, or china clay

Ball clay

Paper clay

Refractory or fire clays:

Glass-pot clay

Flint clay

Plastic fire clay and shales

Graphitic fire clay

Pottery or stoneware clays

Medicinal clay, bentonite, Denver mud

Low-grade clays:

Vitrifying clays and shales:

Terra-cotta clays and shales

Sewer-pipe clay and shale

Roofing-tile clay and shale

Brick clays and shales:

Loess clay

Glacial clay

Pressed-brick clay and shale

Paving-brick clay and shale

Adobe clay

Gumbo

Slip clays

Fuller's earth

High-grade Clays

Whiteware Clays

Kaolin or China Clay (Nonplastic). Kaolins are residual white-burning clays, consisting chiefly of the hydrous aluminum silicates and generally possessing little or no plasticity. Whiteware clays are used for porcelain, china, whiteware, pottery, high-grade tile, and paper manufacture.

Kaolin or China Clay (Plastic). A sedimentary, generally white clay containing a high percentage of kaolinite and little or no iron oxide. Its principal uses are in the manufacture of paper, sanitary ware, and tile. The plastic kaolins are sometimes referred to as china and ball clays and contain more fluxing impurities than the nonplastic kaolins. They are also often called paper clays.

Ball Clays. White-burning plastic clays of high tensile strength and bonding power and little or no iron oxide. They are extensively used as an ingredient of high-grade tile and whiteware mixtures to give the body sufficient plasticity and bonding power.

Paper Clay. A highly plastic white clay, free from sand.

Refractory Clays

Fire Clays. Refractory or fire clays are clays that endure high temperature without change other than dehydration, but the term is frequently misapplied. Many of the best fire clays are nonplastic, this property being supplied by the addition of a small

* SCHRADER, F. C., STONE, R. W., and SANFORD, S., *Useful Minerals of the United States*, U.S. Geol. Survey, Bull. 624, 1917, p. 363.

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quantity of less refractory but plastic material. Comparative freedom from fluxes, such as iron, alkaline earths, alkalies, and excessive silica, is essential. The composition, both chemical and mineralogic, is similar to that of ball clay. The principal uses of refractory clays are for materials required in the industries (especially in iron and steel manufacture and in coke making) where high temperatures must be withstood.

Glass-pot Clay. A variety of refractory clay that, besides possessing refractory qualities, burns dense at a low temperature without warping and has good bonding power.

Flint Clay. A nonplastic, hard, dense refractory clay, having an appearance much like flint, a shell-like fracture, and a composition like plastic fire clay.

Plastic Fire Clays and Shales. Refractory clays and shales that are plastic when wet.

Graphite Fire Clay. A black clay resembling soft coal. It contains about 60 per cent silica and 30 per cent iron and alumina, and burns buff or white. It is used for the manufacture of pressed brick and converter lining and binding. It seems to be a product of the disintegration of graphitic schist or slate.

Pottery Clays

The general term "pottery clays" includes some refractory and vitrifying clays. These clays are, as a rule, semirefractory and burn to a dense mass. High plasticity, tensile strength, and complete retention of form while burning are essential properties. A buff color may be produced, owing to the content of iron or manganese. In ordinary practice a mixture of clays is used. Some of the products are earthen and common stoneware (both plain and decorated), crockery, and glazed ware.

Medicinal Clay

Bentonite, Denver Mud. A bedded or sedimentary plastic clay that swells immensely on wetting. Mixed with glycerin it forms a proprietary medicament known as "antiphlogistine." It is used in medicine and as packing for horse's hoofs; also for paper filling and sizing.

Low-grade Clays

Vitrifying Clays

Vitrifying clays are similar to pottery clays but are composed of lower grade material. They may be semirefractory, should burn dense, and should contain considerable iron, both for color and flux. Fair tensile strength is desirable, as is also low fire shrinkage and low vitrification temperature, with a good range in temperature between incipient and complete fusion.

Terra-cotta Clays and Shales. For terra-cotta ware a semirefractory clay of good grade is preferred. When burnt, low shrinkage and freedom from soluble salts and warping are essential.

Pipe Clays. Almost any fine-grained clay that has a well-developed plasticity and a high percentage of iron, which apparently favors the formation of the necessary glaze, is suitable for pipe clay.

Roofing tile and fireproofing require semirefractory clay or shale, with fair plasticity and tensile strength, that burns hard at a low temperature. Other uses are for enameled brick, hollow tile, and conduits.

Paving Brick. Material for paving brick includes many impure shales as well as semirefractory clays. It should possess fair plasticity and good tensile strength.

Brick Clays

Almost any kind of clay that possesses plasticity can be used for common brick. Red-burning clays are preferable, since they harden at a low temperature. Loess, glacial, and marine clays are also used for this purpose. Brick and draitile are the principal products.

Loess (Clays). The term "loess" is applied to extensive, uniformly fine-grained deposits that are high in silica, low in alumina, and high in alkalies. Their use is confined to common brick and other cheap products. They are of Pleistocene age and are commonly thought to consist of wind-deposited dust. In the Mississippi Valley they are commonly known as "bluff deposit."

Glacial clays are local deposits of generally tough, dense, gritty clays formed directly by the continental glacier or waters issuing from it into flood plains and lakes in the glaciated area of the northern United States. Those formed directly by the ice, as a rule, contain many stones. Some of the glacial clays, as in the state of Michigan, are used extensively in the manufacture of cement and pottery, as well as brick.

Pressed Brick. A fairly good quality of clay or shale is required for pressed brick. The shrinkage in air and fire must be low and the temperature of vitrification moderately low. For light-colored brick a semirefractory clay is used.

Adobe Clays. Adobe clays are surface clays that are high in lime, and hence can be used for but few products, the chief of which is adobe or sun-dried brick.

Gumbo Clays

The term "gumbo clays" is applied to fine-grained, plastic, tenacious surface clays of recent formations. Their occurrence along stream channels in the western central states suggests a relation to loess. The burned product is used largely for railroad ballast, but in some places also for brick.

Slip Clays

Slip clays are used for glazing. They possess the properties of fineness of grain, high percentage of fluxing impurities and low shrinkage in air, low temperature of fusion, and early maturity in burning. Their use on different clays calls for a wide range in physical properties. Color is of secondary importance, since it is more or less under control.

Distribution of Clay Deposits. It is, of course, impossible to describe or even to enumerate all the known clay deposits of probable commercial value. Even if it were possible, the list would serve no useful purpose. Clays suitable for the manufacture of the lowest grades of clay products are exceedingly abundant and widespread. Thus, the value of such deposits depends chiefly upon the local market for brick and the accessibility of cheap fuel. But deposits of suitable clays for the higher grade clay products are less common and less widely distributed. The finished products are of greater unit value. Therefore, higher prices may be paid for the crude clay and it will bear higher transportation charges. For the highest grades of clay products, such as chinaware and porcelain, the deposits of suitable clays are relatively scarce. The raw clays are of considerable value and may be shipped long distances.

It is customary to divide all clay products into two general classes: (1) pottery products, including chinaware, porcelain, wall and floor tile, etc., in which high-

grade white-burning clays are used; and (2) heavy or structural clay products, which include common, fire, and paving brick, draintile, sewer pipe, etc., and in which lower grade, nonwhite-burning clays are used. In general, the high-grade, white-burning clays (including paper clays) are relatively scarce, and the low-grade brick, sewer-pipe, and refractory clays are relatively abundant. Notable exceptions to the latter statement are the refractory clays used in making glass pots and other glass-house refractories, and those used for graphite crucible manufacture. References 7, 12, and 49 are useful in the study of distribution. Many undeveloped deposits of clay of industrial value undoubtedly exist in areas deficient in transportation or a consuming population.

Mining and Preparation. *Low-grade Clays.* The low-grade clays, except for some fire clays, stoneware clays, etc., of higher value, are nearly always excavated by open-pit methods, for they are of such low-unit value that they cannot stand the higher costs of underground mining.

The brick clays as now worked usually occur in bedded deposits, either at the surface or under a relatively light overburden. If stripping is necessary, it may be done by pick-and-shovel methods, by horse-drawn drag or wheel scrapers, by dragline scraper, by dragline excavator, by hydraulic methods, or by steam shovel. After the overburden is removed, the clay is excavated by one of the methods just noted for stripping. In general, it may be said that in the past simple hand methods have been the most common, but there is now a growing tendency toward the use of labor-saving equipment. The handling of clay mechanically may be difficult, especially in wet weather, due to its stickiness. Hand methods of excavation have an advantage where the clays are pockety or are lacking in uniformity, in that sorting may be done.

Ordinarily, brick clays receive little or no preparation prior to use, except a thorough mixing, which is really part of the manufacturing process.

Fire clays and certain other types of clays and shales may be of sufficient value to permit underground mining. The mines may be opened either by tunnels or by shaft, and the clay is generally removed by hand methods, using the room-and-pillar system. These methods often closely resemble those used in coal mining.

High-grade Clays. High-grade clays (kaolins, ball clays, and sedimentary "kaolins") are mined by at least three general methods: (1) open-cut mining; (2) "shafting"; and (3) underground mining.

In open-pit mining the overburden must first be removed. In small residual kaolin deposits this is generally done by hand, but the heavy overburdens of the sedimentary "kaolin" deposits of the Langley, S.C., district are removed by dragline scrapers. The clay then may be excavated in one or more benches by hand methods (which allows sorting) or by hydraulic methods. Some of the residual kaolin in western North Carolina and nearly all the kaolin from the Cornwall district of England are mined by hydraulicking. In this method the clay is washed down by jets of water, and the clay-water suspension is raised to the surface by pumping (or in bucket elevators, as at a mine near Spruce Pine, N.C.) and allowed to flow by gravity through launders or pipes (or pumped through pipes) to the refining plants.

In some cases kaolins are removed by ordinary methods of underground mining,

the mines being opened either by shafts or by tunnels. Timbering is usually required, and if the ground is very wet considerable difficulty may be encountered from squeezing or caving.

If the kaolin must be washed before shipping it is usually transported to the refining plants, in a water suspension, through inclined wooden troughs or flumes.

Residual kaolins are usually found mixed with considerable quantities of mica, silica, and even undecomposed feldspar. These impurities must all be removed before shipping. The details of the refining methods vary, but all plants more or less closely follow the principles outlined below. The clay-water suspension or "slip," as it is called by clay workers, is passed through long, narrow, shallow, slightly inclined troughs, called "sand troughs," where the sand and coarser grains of mica settle out. The sand is removed from the trough by hand shovels or a mechanical device called a sand wheel. The slip then passes through another and longer set of troughs, set at a slighter inclination. In these troughs, called "mica troughs," or simply "micas," most of the finer mica settles out and is saved as a valuable by-product. The suspension next passes over a fine screen to remove very thin mica flakes, still held in suspension, and into large settling tanks where the kaolin is allowed to settle out.

Sometimes an electrolyte—sodium carbonate, for example—is added to the clay slip before it goes to the sand troughs, in order to deflocculate the clay and assist the settling of the sand. Later a coagulating agent, such as alum, may be added in the settling tank to coagulate the clay and hasten its settling. By the careful use of the proper electrolytes and flocculating agents at the proper times, the grade of the clay may sometimes be greatly improved.

From the setting tanks the thickened clay slip is drawn off into an agitator and then is pumped to a filter, either of the intermittent leafpress type or of the continuous-rotary type, such as the Oliver or Portland filters. The filter cake is dried in the open air on racks in drying sheds (little used now), or on drying floors the bottom of which are covered with steam-pipe drying coils, or in rotary driers of various types, or on drying cars in tunnel kilns.

The methods noted above represent older practice that has been superseded in more modern plants. Recently built plants for refining residual kaolins utilize concentrating tables and jigs, rake and bowl classifiers, vibrating screens, froth flotation, and other modern equipment and processes.^{119,126,129,131} High grade finely ground mica forms a valuable by-product at some of the residual kaolin plants.

Some of the high-grade kaolins and ball clays do not require washing. They are dried, ground, and screened by various types of equipment to desired size. Tyler¹³¹ has described a modern operation located in South Carolina. The clay is delivered to storage from whence it is loaded to a "slicer," where it is shredded by impact with steel knives. The material is then dried and ground in a Raymond mill. The fines are bagged for shipment and the rejects taken to an air classifier. The fines from this are returned for grinding and the coarse rejects conveyed to waste. The final product is 325-mesh material suitable for the rubber trade.

Prices. In 1950, kaolin was quoted in Florida at \$18.75 per ton for crushed material and \$24.25 for pulverized. Georgia kaolin for filler and ceramic use was quoted at \$8.50 to \$9.50 for crushed material and \$13 to \$17 per ton for pulverized in paper bags. North Carolina kaolin, bulk, in carloads was \$18 to \$20 per ton, depending on type. Tennessee ball clay was \$10 per ton crushed and \$19.50 for purified material in bags. Prices vary with locality and quality, as demonstrated by industrial acceptance. For example, high-grade paper-coating clays may sell at up to \$35 or more per ton.

Specifications and Tests. There are practically no standard and generally accepted specifications for clays of any type or for any use. Many consuming companies have general standards for certain clays, but these specifications are usually drawn to suit their own peculiar needs. Clays are not ordinarily sold on specification, but upon actual inspection and test by the consumer. Even methods of testing are not standardized. Various standard methods of testing have been suggested, and tentative standards have been drawn up by the American Ceramic Society.

As has been noted before, the value of a clay or the specific use for which it may be best adapted cannot be determined by inspection or by analysis. It is obvious that by visual inspection, certain low-grade, impure clays may be discarded for high-grade uses, but a clay of apparently medium or high grade must be subjected to detailed ceramic tests (unless it is to be used in the unburned state) by experienced ceramic chemists.

When clay is to be used in the unburned state, that is, as a filler, for example, it is usually tested by the consumer in his own laboratory, by methods that he has developed to suit his own needs. In many cases these methods vary in different plants manufacturing the same type of product, and a clay found suitable by one company may be rejected by another.

Clay used as a filler in paper, paint, rubber, linoleum, oilcloth, phonograph records, and so on, must usually fulfill most or all of the following qualifications:

It must have a very fine *grain size*. For example, some rubber manufacturers require fillers so fine that 98 per cent will pass through a 300-mesh sieve. Moreover, it must be free from coarse particles.

It must be free from, or very low in, free silica or other gritty impurities. This is particularly applicable to paper fillers and for phonograph records.

It must be of a very pure, clear, brilliant white color—particularly important in paint, paper, and white oilcloth.

It must show a low oil absorption—particularly important in paint, linoleum, and oilcloth.

Paper fillers must show a high percentage of retention in the finished paper.

For special purposes other properties may be demanded.

Production, export, and import data relative to clay in the United States are shown in Table 3.

Imports of clay in the United States have declined since 1914. In that year a total of 398,100 tons were imported; 328,038 tons of this figure was represented by kaolin: The First World War resulted in the curtailment of imports and an increase in the recognition of the possibilities of domestic supplies. Domestic

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substitutes were developed for foreign clays previously considered indispensable. This trend continued for years, and imports are now of minor importance in the clay industry as a whole. English kaolins in Devon and Cornwall have enjoyed some prestige due to their uniform high grade and possibly due to the early development of the ceramic industries by English potters in the United States. The English industry can produce approximately 800,000 tons per year; about two-thirds of this production must be sold in export markets.

TABLE 3. SALIENT STATISTICS OF THE CLAY INDUSTRY IN THE UNITED STATES, 1947 TO 1948

	1947		1948	
	Short tons	Value	Short tons	Value
Domestic clay sold or used by producers:				
Kaolin or china clay.....	1,425,106	\$17,107,963	1,568,848	\$19,756,738
Ball clay.....	269,050	2,923,760	298,979	3,342,647
Fire clay, including stoneware clay.....	9,038,680	26,208,602	9,849,914	29,424,034
Bentonite.....	763,889	5,949,586	921,560	7,136,308
Fuller's earth.....	329,068	4,660,614	342,081	5,273,851
Miscellaneous clays.....	21,773,680	17,422,962	24,764,599	20,414,694
	33,599,473	\$74,273,487	37,727,981	\$85,348,272
Imports:*				
Kaolin or china clay.....	82,628	\$ 1,330,001	99,930	\$ 1,650,102
Common blue and Gross-Almerode.....	25,849	342,711	32,195	460,422
Fuller's earth.....	155	3,001	129	2,092
Other clay.....	3,768	43,450	3,687	29,454
	112,400	\$ 1,719,163	135,941	\$ 2,142,070
Exports:*				
Kaolin or china clay.....	18,686	\$ 234,707	19,074	\$ 319,294
Fire clay.....	110,193	780,993	102,482	935,232
Other clay (including fuller's earth).....	138,244	3,587,489	145,292	3,883,050
	267,123	\$ 4,603,189	266,848	\$ 5,137,576

* Figures on imports and exports compiled by M. B. Price, of the Bureau of Mines, from record of the U.S. Department of Commerce.

The distribution of kaolin production is presented in Table 4 and that of ball clay in Table 5.

Fire clay is discussed in the section dealing with refractories and bentonite and fuller's earth in the sections concerned with these products.

Utilization. The utilization of clay presents too complex a pattern to permit discussion. It is represented best by Table 6.

Clays are of prime importance to the ceramic and refractory industries. It

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will be noted, however, that their use in nonceramic industries is wide spread and amounts to a very substantial tonnage.

TABLE 4. KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY STATES

State	Sold by producer		Used by producer		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1945						
California.....	6,385	\$ 72,418	1,901	\$ 8,182	8,286	\$ 80,600
Georgia.....	629,531	6,278,411	72,857	406,116	702,388	6,684,527
Pennsylvania.....	13,965	50,589	.....	.....	13,965	50,589
South Carolina....	159,550	1,467,328	.....	.....	159,550	1,467,328
Undistributed* ...	55,799	789,883	.....	.....	55,799	789,883
	865,230	\$ 8,658,629	74,758	\$414,298	939,988	\$ 9,072,927
1946						
California.....	†	†	†	†	18,254	\$ 152,898
Georgia.....	815,367	\$ 9,106,878	102,385	\$564,171	917,752	9,671,049
Pennsylvania.....	†	†	†	†	42,186	147,262
South Carolina....	†	†	†	†	270,016	2,493,031
Undistributed† ...	376,124	3,805,989	28,427	76,729	74,095	1,089,527
	1,191,491	\$12,912,867	130,812	\$640,900	1,322,303	\$13,553,767

* Includes Alabama, Florida, Illinois, North Carolina, Utah, and Virginia.

† Included with "Undistributed."

‡ Includes Alabama, Florida, Illinois, Maryland, North Carolina, Utah, Virginia, and figures indicated by footnote †.

TABLE 5. BALL CLAY SOLD BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value
Kentucky.....	72,729	\$ 669,419	80,077	\$ 744,599	98,918	\$ 990,301
Maryland.....	9,599	82,380	11,612	92,987	12,538	106,208
New Jersey.....						
Tennessee.....	73,339	624,297	82,835	752,289	131,689	1,299,393
	155,667	\$1,376,096	174,524	\$1,589,875	243,145	\$2,395,902

Nonceramic Uses. The variety of industries, other than the ceramic, in which clays are important is indicated in Table 6. It is noteworthy that the tonnage of kaolin used in the paper and rubber industries greatly exceeds that used in the manufacture of pottery products. In 1946, 53 per cent of the total kaolin production was used as paper filler and coating, 12 per cent in rubber, 10 per cent in

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TABLE 6. CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1946, BY KINDS AND USES, SHORT TONS

Use	Kaolin	Ball clay	Fire clay and stoneware clay	Bentonite	Fuller's earth	Miscellaneous clay including slip clay	Total
Pottery and stoneware:							
Whiteware, etc.	107,295	205,015	5,371				317,681
Stoneware, including chemical stoneware			36,256				36,256
Art pottery and flower pots	4,242	10,631	19,197			32,739	66,809
Slip for glazing						3,083	3,083
Total	111,537	215,646	60,824			35,822	423,829
Tile, high-grade	14,321	17,104	114,975			11,879	158,279
Kiln furniture:							
Saggers, pins, stilts	10,039	2,000	30,484				42,523
Wads			3,198				3,198
Total	10,039	2,000	33,682				45,721
Architectural terra cotta		1,729	3,232				4,961
Paper:							
Filler	448,756						448,756
Coating	248,527						248,527
Total	697,283						697,283
Rubber	162,393		11,006			1,945	175,344
Linoleum and oilcloth	13,323	258	4,463				18,044
Paints:							
Filler or extender	21,835		532			283	22,650
Calcimine	393						393
Total	22,228		532			283	23,043
Cement manufacture	47,559	328	22,218	25		4,772,910	4,843,040
Refractories:							
Firebrick and block	123,300		3,351,790				3,475,090
Bauxite, high-alumina brick			89,774				89,774
Fire-clay mortar, including clay processed for laying firebrick	1,912		222,391				224,303
Clay crucibles	4,379	120	1,238				5,737
Glass refractories	293	515	18,519				19,327
Zinc retorts and condensers			56,648			250	56,898
Foundries and steelworks	2,373		678,161	165,044		22,052	867,630
Other refractories	451		528,323				528,774
Total	132,708	635	4,946,844	165,044		22,302	5,267,533
Heavy-clay products, common brick, face brick, paving brick, draintile, sewer pipe, and kindred products	10,481		2,597,819			14,790,298	17,398,598
Miscellaneous:							
Rotary drilling mud			467	231,252	9,776	196,662	438,157
Filtering and decolorizing oils (raw and activated earths)				144,221	227,088*		371,309
Other filtering and clarifying				5,968	2,992		8,960
Artificial abrasives	10,213	648	411			206	11,478
Absorbent uses (oily floors, etc.)	167				49,036		49,203
Asbestos products	2,582						2,582
Chemicals	20,996		71,252	600			92,848
Enameling	10	258	100				368
Filler (other than paper or paint)	31,337			3,522	117		34,976
Insecticides	19,305			5,279	5,558	919	31,061
Plaster and plaster products	8,148		1,336				9,484
Concrete admixture, sealing dams, etc.				1,227			1,227
Other uses	7,673	4,539	38,813	44,290	4,185	357,118	456,618
Total	100,431	5,445	112,379	436,359	298,752	554,905	1,508,271
Grand total, 1946	1,322,303	243,145	7,907,974	601,428	298,752	20,190,344	30,563,946
Grand total, 1945	939,988	174,524	6,090,411	573,998	296,368	10,848,686	18,923,975

* Comprises following: Mineral oils, 202,722 tons; vegetable oils, 24,366 tons.

refractories, and 8 per cent in pottery. As a filler kaolin possesses the advantages of natural fine grain size, inertness, uniformity, white color if desired, and low cost.

In the paper industry it is essential that the clay have a high retention in the paper fibers, meet standards of color and brightness, and be low in quartz and other abrasive impurities that cause excessive wear on paper machine wires and result in products which dull the cutting edges of fabricating machines. Modern paper laboratories have testing machines that measure abrasion wear on wire screen cloth. A rough test is to rub a piece of copper with the clay to be tested. Rapid polishing indicates a high content of abrasive material.

Most of the kaolin for paper filling and coating produced in this country comes from Georgia and is produced by wet milling methods. After preliminary degrading in rake classifiers the clays are bleached with zinc or sodium hydrosulfite. The clay is then sized, in the largest and best plants, in Bird centrifuges,¹²⁶ which are capable of making uniform products with an average grain size as small as 2μ . The centrifuge has revolutionized the production of paper filler and coating clays in this country. The finest products are sold for paper coating and the coarser fractions for paper filling. The thickened clays are filtered in filter presses or other devices, and the semidry clay is dried in rotary or continuous-pandriers.

Paper-coating clay is used to produce smooth, opaque surfaces on paper for high-fidelity printing. The clay must have a fine grain size, spread evenly, polish well, and have good printing characteristics. The testing of paper coating clays is a very exact and extensive operation.¹⁴⁹

Other important nonceramic uses are as follows:

1. As a filler in all grades of rubber goods from automobile tires to pressed and molded goods and hard-rubber goods.
2. As a filler and stiffener, when mixed with size, for cotton cloth and other textile fabrics.
3. In paint, as an inert extender; in whitewash; in distemper paints.
4. In linoleum and oilcloth as a filler and as a surface coating.
5. As a filler in many different products, such as phonograph records, white celluloid goods, papier-mâché, prepared modeling compounds, soap, asbestos products, packing materials, wall plasters, and insecticides.
6. As a mild abrasive in polishes, tooth powders, cleaning soaps and soap compounds, and so on. (Such clays should contain a considerable proportion of very finely divided quartz.)
7. In the manufacture of colored "chalk" and crayons.
8. In the manufacture of ultramarine.
9. In the preparation of drilling mud used by rotary drill rigs in the production of petroleum.
10. As a filtering and clarification medium. Efficiency is increased by activation with sulfuric acid.
11. As an essential raw material in the manufacture of portland cement, where it supplies the necessary SiO_2 and Al_2O_3 . Clay may be present in the limestone, such as the cement rock of the Lehigh Valley, or it may be secured from separate operations in clay beds or shale deposits.

12. As an adsorbent, precipitation base, or extender in many chemical products.
13. As a source of alumina for making aluminum sulfate and the alums.
14. As a possible source of alumina for making metallic aluminum.

During the Second World War the shortage of bauxite resulted in renewed efforts to use clay as an ore of aluminum. Material with a minimum alumina content of 35 per cent was required. This was obtainable with ease, but the production costs of aluminum discouraged the survival of the process in postwar industry. The diaspora clays, with their high alumina content (frequently over 50 per cent), were also considered.

Meta-kaolin (calcined kaolin) has been produced, and its possibilities as a mild abrasive and a base-exchange medium examined.

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CORDIERITE

Composition. Cordierite or iolite is essentially a silicate of magnesium and aluminum. Authorities differ as to its theoretical composition. Dana's *Mineralogy** gives the formula $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$ or $H_2O \cdot 4(Mg,FeO) \cdot 4Al_2O_3 \cdot 10SiO_2$. This has a percentage composition of SiO_2 , 49.4 per cent; Al_2O_3 , 33.6

* DANA, JAMES, and SALISBURY, EDWARD, "The System of Mineralogy," 7th ed., John Wiley & Sons, Inc., New York, 1944.

per cent; Fe_2O_3 , 5.3 per cent; MgO , 10.2 per cent; and H_2O , 1.5 per cent. For artificial material containing no iron or water there has been given the formula² $2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$; SiO_2 , 51.4 per cent; Al_2O_3 , 34.9 per cent; MgO , 13.7 per cent.

General Description. Cordierite occurs in massive form resembling quartz. It is commonly associated with metamorphic rocks such as gneisses, schists, and slate. At Bodenmais, Bavaria, it is present in sufficient quantity in the local rocks to justify their classification as cordierite gneisses. It displays very strong pleochroism in various shades of blue. The change of color with direction is so pronounced as to be visible to the unaided eye.

Physical Properties. *Hardness*, 7 to 7.5. *Specific gravity*, 2.6 to 2.7. *Melting point*, fuses at 5. *Index of refraction*, 1.538 to 1.597. *Color*, pale to dark blue. *Streak*, white. *Luster*, vitreous. *Cleavage*, imperfect. *Transparency*, transparent to opaque.

Occurrence. Occurrences of cordierite in place have been restricted to the metamorphic rocks and their environment. Pebbles, particularly of the variety known as iolite, have been found in the gem gravels of Ceylon. Little commercial interest was shown in this mineral until research showed that a synthetic compound, artificially produced, was of value in the ceramic industries. This has led to an increased interest in the properties and occurrence of the natural mineral. If large deposits of the natural mineral could be found, particularly if low in iron, they probably would be of commercial interest.

Utilization. The iolite variety has been employed to a limited degree as a gem stone. Material originating in Ceylon has been favored for this use. Transparent specimens are rare and the stone has been cut in cabachon or rounded forms. The blue color in a polished surface makes an attractive gem. The best of this type of material is known as "water sapphire."

In ceramics cordierite bodies are of value where exceptionally low coefficient of expansion and good thermal shock resistance are of importance, for example, thermocouple insulators, burner tips, heater radiants, oil-burner ignition insulators, etc. Cordierite bodies may be made from mixtures of talc, clay, and aluminum oxide; from talc and clay; or from sierralite and kaolin. Sierralite is a hydrous magnesium aluminum silicate produced in California.² It consists approximately of about 36 per cent silica, 24 per cent alumina, 24 per cent magnesia, and 12 per cent combined water plus small amounts of iron oxide, lime, etc., as impurities. A 50-50 mixture of sierralite and kaolin gives nearly a theoretical cordierite analysis, but additions of 5 to 20 per cent zircon extends the firing range.

Artificial cordierite has also been prepared from mixtures of pyrophyllite and magnesium chloride.

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CORUNDUM AND EMERY

General. These minerals, once of considerable importance, have now been largely replaced by the artificial abrasives silicon carbide and electrically fused alumina. For a few special uses they have been considered more or less essential, but they are gradually being replaced, even in these uses, by improved types of artificial abrasives. Since they are now largely only of historical interest little space will be devoted to them here. Descriptions of the once-important deposits and processes may be found in the references given in the bibliography.

During the Second World War essential uses for corundum for snagging wheels and for grinding and polishing precision lenses led to a world-wide search for corundum and stimulation of production by government agencies. This intensive effort resulted in negligible production in this country, in Canada, and in England. In the Union of South Africa, the world's largest prewar source of corundum, this stimulation resulted in some increased production, but by 1946 production had declined greatly. From this we may conclude that a domestic corundum industry cannot be supported from presently known deposits and that world production has nearly ceased to be important. The production of domestic emery, from the single source near Peekskill, N.Y., however, continues at a little above the pre-war rate.

Composition. *Corundum* is alumina, Al_2O_3 :Al, 52.9 per cent; O, 47.1 per cent. *Emery* is alumina mixed with the oxides of iron (Fe_2O_3 or Fe_3O_4).

General Description. Corundum, the second hardest mineral known, is found in barrel-shaped hexagonal crystals; also in compact granular and lamellar masses. The transparent crystalline varieties, sapphire and ruby, are very valuable as gem stones. Emery is opaque granular corundum intimately mixed with hematite or magnetite, quartz and spinel, usually dark gray or black in color. Emery may contain as low as 60 per cent corundum.

Physical Properties. *Hardness*, 9 (emery 7 to 9). *Specific gravity*, 3.9 to 4.1. *Melting point*, above 1950°C . *Index of refraction*, 1.760 to 1.768. *Color*, gray, blue, red, green, yellow, black, brown, white, or colorless. *Streak*, white. *Luster*, vitreous or adamantine. *Cleavage*, basal with nearly rectangular rhombohedral partings, conchoidal fracture. *Transparency*, transparent to opaque. *Tenacity*, brittle to tough.

Occurrence. Corundum usually occurs disseminated in crystalline limestone and dolomite, gneiss, mica, and chlorite schist, nepheline syenite, granite, peridotite, and in pegmatites; also as grains and pebbles in placers. Emery occurs in crystalline limestones and schists, in peridotite, and associated with chlorite and margarite in amphibolite schists. The best known deposits of corundum are in Canada, India, Union of South Africa (Transvaal), Madagascar, and the United States. The principal emery deposits are in Greece (Naxos, etc.) and near Smyrna, Asia Minor; but some production has come from Peekskill, N.Y., Chester, Mass., and Whittles, Va.

Union of South Africa (Corundum). In northern and eastern Transvaal, Union of South Africa, corundum fields occupy an area of some 2,000 sq miles in the Pietersburg and Zoutspansberg districts. There are two main fields: the Plateau region, centering about Bandolierkop, and Mara, served by the Messina Railway and the Low Country region on the Selati Railway mainly east of Mica Siding. There are three main varieties, all being exploited commercially: (1) crystal corundum, consisting of loose crystals in shallow alluvial deposits; (2) boulder corundum, or loose blocks consisting of a core of corundum in a matrix of more or less altered plagioclase feldspar; (3) reef corundum, consisting of vertical veins several feet thick intrusive into a basic formation of highly felspathic plumasite or a margarite-corundum body, marundite. The corundum content of the plumasite and marundite ore bodies is 30 to 60 per cent. Deposits have also been developed in a small way near Steinkopf, in Namaqualand, Southern Rhodesia, Mozambique (Portuguese East Africa), Nyasaland, and Tanganyika.

Canada (Corundum). Important deposits of corundum occur in Canada in the corundum syenites, anorthosites, pegmatites, etc., in Hastings, Renfrew, Haliburton, Peterborough, Frontenac, and Lanark counties in central Ontario. The corundum-bearing rocks occur as three distinct bands, the longest of which is about 103 miles long with a northeast-southwest strike and a maximum width of nearly 6 miles. The other bands, parallel to the first, are 8 and 12 miles long, respectively, and the total distance between the outer bands is about 75 miles. The corundum content ranges from less than 1 up to 75 per cent. The mill recovery at Craigmont over a period of 2 years averaged 10.41 per cent corundum. Individual crystals range from microscopic size to masses weighing 30 lb, the crystals measuring 2 or 3 in. long as a possible average. Deposits have been developed and mined at the Burgess mines (Jewelville P.O.) in Carlow Township, Hastings County, and at Craigmont in Raglan Township, Renfrew County. The peak of Canadian production was reached in 1906 and 1907, when 2,500 and 3,000 tons of graded grain were sold. From 1919 to 1921 mill tailings were treated at Craigmont. From 1921 to 1944 there was no Canadian production. Late in 1944 the U.S. Foreign Economic Administration built a mill at Craigmont to re-treat the old mill tailings, and for a year or two there was a small, uneconomic production.¹⁶

India (Corundum). Some of the most extensive corundum deposits of the world, both of ordinary corundum and of the gem varieties, occur in India. The following provinces and native states are said to contain more or less extensive deposits: Afghanistan, Assam, Bengal, Burma, Central Provinces, Hyderabad,

Kashmir, Madras, Mysore, Punjab, Rewah, and Travancore. The principal production has apparently come from Assam, Mysore, Madras, Rewah, Hyderabad, and Kashmir. Massive corundum in the form of large blocks weighing several tons, disseminated crystals in solid rock, and loose grains and crystals in clays and sands all seem to have been productive. However, in spite of intensive efforts during the Second World War, production of only a few hundred tons was achieved. While reserves are reported to be large, costs are very high due to the extreme inefficiency of local hand labor, inadequate transportation, and lack of mining and milling equipment.

Madagascar (Corundum). Corundum, both gem and abrasive varieties, occurs in Madagascar in the alluvial deposits of Mevatanana, Ambositra, and Betafo. Some corundum has been shipped from Madagascar, but descriptions of the deposits are very meager.

United States (Corundum and Emery). Corundum occurs in many states, mostly in the East, but commercial production of abrasive corundum has practically been confined to North Carolina, Georgia, and Montana. Prior to 1906 a relatively small amount of corundum was produced at various times in North Carolina at Corundum Hill, Macon County; Buck Creek, Clay County; and near Sapphire, Jackson County. In Georgia it was produced at the Laurel Creek mine in Rabun County. In Montana, a small amount of abrasive corundum has been produced near Salesville, Gallatin County. From 1906 to 1914 there was no domestic production of corundum due to the superiority of artificial abrasives, but in 1915 production at Corundum Hill, N.C., was revived in a small way. In 1917 and 1918, due to war demands, three operators reported production in North Carolina, but there was no further production until 1943. During the war years governmental efforts resulted in minor experimental shipments from North and South Carolina, Montana, and in Douglas County, Nev., but no results of commercial importance were achieved.

Emery has been produced in the United States in three localities. (1) The deposits at Chester, Hampden County, Mass., were the first to be worked. Discovered in 1864, for many years they furnished practically the entire emery production of this country. They were abandoned as exhausted in 1913. (2) In Virginia, near Whittles, Pittsylvania County, deposits of high-grade spinel emery, said to be equal to medium grade Naxos emery, were mined on an important scale for about 11 years, beginning in 1917, but there has been no production in recent years. (3) The most important emery deposits in this country have been those in and near Peekskill, Westchester County, N.Y. These deposits, opened in 1883, have been in more or less continuous production ever since. The ore here is a massive black or gray, hard, fine granular spinel emery. Production reached its peak in 1917 (nearly 16,000 tons), gradually declined to a few hundred tons per year (zero in 1938), but again increased to a maximum of nearly 8,000 tons (1945) just following the Second World War. 1948 production was 5,405 tons valued at \$69,408. It is marketed as both crude rock and grain to makers of abrasive wheels, stones, and polishing compositions. Considerable quantities are also sold as a nonslip, wear-resistant component of concrete floors and stair treads.

Sapphire corundum has been mined on a considerable scale in Montana at Yogo Gulch, Fergus County, and at a few other localities. The Yogo Gulch mine yielded both gem sapphires and nonprecious sapphire crystals for the manufacture of watch "jewels" and other "jewel" bearings.

Greece (Emery). The Greek emery deposits occur on the islands of Naxos, Heraklia, Sikinos, Samos, Nikaria, and Chios. The most important of these deposits are those of Naxos in the Amomaxi district near the village of Bothris (Wothri) and also in the Koxaki district. The emery occurs in great abundance as a hard massive rock, both in the form of huge boulders in a red soil and as lenticular masses in a crystalline limestone. Much of the production in the past has come from the loose boulder deposits. The principal port of shipment is Syra. Naxos emery is considered the best and purest in the world.

Turkey (Emery). The emery deposits in Asia Minor are in the province or vilayet of Aidin, of which Smyrna is the principal city and shipping point. Emery is found in several localities here, but the most important are about 12 miles southeast of Ayasaluk (ancient Ephesus) on the slopes of the Gumach Dag Mountains, and from Ak Sivri about 100 miles southeast of Smyrna. The deposits are of two kinds: (1) rock emery in lenticular masses in crystalline limestone; and (2) emery drift or detritus, consisting of loose fragments or boulders in a compact clay. The main source of supply in the past seems to have been the detrital deposits. "Turkish" emery is not considered of as high grade as that from Naxos.

Other Countries. Massive corundum, emery, and gem corundum (ruby and sapphire) are known to occur in many other localities in many countries, but commercial production has been unimportant and the deposits cannot be considered here.¹

Production and Consumption. As has been noted elsewhere, the demand for hard abrasives is today taken care of very largely by artificial abrasives (nearly 63,000 tons of silicon carbide and about 155,000 tons of aluminum oxide in 1948). Imports of crude corundum in recent years reached a peak of 6,402 tons valued at \$437,306 in 1944 and declined to 4,207 tons valued at \$340,891 in 1946. There were no imports of emery during the war years, but imports of crude emery in 1946 were 2,561 tons valued at \$33,358. Imports of corundum and emery grain and of finished products, such as wheels, stones, etc., now total less than 100 tons. With no domestic production of corundum and with only about 6,000 tons per year of emery it is evident that the total consumption of these natural abrasives is less than 15,000 tons per year, or less than 8 per cent of the consumption of the artificial abrasives that have replaced them.

Prices. In 1949 corundum was quoted according to size as follows:

<i>Size</i>	<i>Cents per Pound</i>
8-60	8.50
70-275	9.50
500	28.0
850	43.0
1,200-1,600	65.0
2,600	70.0

Emery was quoted per ton of crude ore fob New York at \$12. Emery in 350 kegs, fob Pennsylvania, was quoted at 10 cents per pound for Turkish and Naxos grain and 6.5 cents per pound for domestic.

Specifications and Tests. There are no recognized standard market grades of corundum or emery. Their value depends upon their purity, hardness, and toughness. In general, crystal corundum is more valuable than block corundum. Naxos emery is considered decidedly superior to Turkish emery. There are no standard methods of testing these materials. An ordinary chemical analysis alone is likely to be misleading, for the alumina content may consist not wholly of corundum, but, instead, partly of alumina from impurities such as the various aluminum silicates. While chemical analyses are sometimes made, the general appearance and the physical properties are the governing factors.

Various quick tests for determining abrasive value have been suggested, but these do not give results in accord with actual practice. Most buyers judge first by general appearance. If the material passes this test, it is then usually made into abrasive wheels or coated abrasives, and the behavior and grinding efficiency determined by actual use. Corundum should be pure and tough, but it should have the property of disintegration under pressure into particles with sharp cutting edges. If it is too tough, the edges will wear away and become dull without breaking apart to produce fresh cutting edges.

For abrasive purposes corundum should have a bright and glassy luster—not dull; the broken grain should be angular, uneven, and sharp; cleavage or parting planes should be absent or nearly so; there should be no inclusions of other minerals; as a general rule large crystals are better than very small ones.

During the latter part of 1945, exports of corundum from South Africa were limited, as far as possible, to the following:

Crystal corundum, in grades designated A-1, A-2, B-3, and C-4.

Corundum concentrates, processed through milling, jigging, or other devices in concentrating plants, acceptable to the American Abrasive Co. as crystal grade.

Boulder grade, all corundum ores and concentrates containing less than 85 per cent and more than 70 per cent Al_2O_3 .

The South African government controlled sizes and grades of crystal corundum. Their grades most in demand in the American trade were as follows: A-1, minimum of 92 per cent Al_2O_3 and diameter of $\frac{1}{2}$ in. or over; A-2, minimum of 92 per cent Al_2O_3 and diameter of $\frac{1}{4}$ to $\frac{1}{2}$ in.; B-3, minimum of 90 per cent Al_2O_3 and diameter of $\frac{1}{8}$ to $\frac{1}{4}$ in.; C-4, minimum of 85 per cent Al_2O_3 and diameter of $\frac{1}{8}$ in. or over. All size measurements are on round-hole screens.

Utilization. Before the advent of artificial abrasives, corundum and emery were the hardest and most efficient abrasives known, except for diamond. Today, except for a few very specialized uses, the artificial abrasives are universally accepted as being more efficient and much better adapted to modern production methods than the natural abrasives. For snagging wheels for finishing iron and steel castings corundum wheels give a higher rate of production than wheels made from artificial abrasives, due probably to the way in which corundum grains gradually break down to expose new cutting edges in contrast to the rounded wear of the tougher artificial abrasive grains. Natural corundum grains and dust

have been considered superior to artificial abrasives for the grinding and polishing of precision lenses, probably for the same reason. Artificial abrasives are constantly being improved, and it is probable that eventually they will replace the natural abrasives even for these special uses.

A new use for emery grain developed in recent years is as a component of non-skid concrete surfacing for floors and stair treads.

The most important former uses for corundum and emery, some of which continue to a limited degree, are as follows:

1. *In Solid Blocks.* For rock-emery grinding mills, used in grinding paint and in the fine-grinding of talc, whiting, barite, graphite, etc.

2. *As Loose Grains and Dust.* For abrasive saws and other tools used in cutting and finishing minerals, rocks, and decorative stones; for roughing and polishing metal and rock sections for microscopic examination; for grinding fine lenses; and for other grinding and polishing purposes where the abrasive is most conveniently used in grain or powdered form.

3. *In the form of coated abrasives*, such as emery paper and cloth.

4. *In the Manufacture of Abrasive Wheels.**

5. *Abrasive stones,** for tool sharpening, are made in much the same way that wheels are made, but the vitrified type is by far the most important.

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* See also Abrasives and Garnet.

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CRYOLITE

Composition. Cryolite is sodium aluminum fluoride, Na_3AlF_6 : Na, 32.8 per cent; Al, 12.8 per cent; F, 54.4 per cent. The fluorine content is the highest of any fluorine-bearing mineral obtainable in commercial quantities.

General Description. Cryolite, or kryolith (sometimes called icestone or eistein) is usually found in compact, granular or cleavable masses, but may occur in groups of triclinic crystals resembling cubes. It is soft, waxy, and translucent, and when white often resembles paraffin.

Physical Properties. *Hardness*, 2.5 to 3. *Specific gravity*, 2.9 to 3. *Melting point*, 2 in scale of fusibility. *Index of refraction*, 1.364. *Color*, colorless, white, black, brown, and reddish. *Streak*, white. *Luster*, pearly on basal pinacoid but vitreous to greasy or waxlike elsewhere. *Cleavage*, basal and prismatic at nearly right angles. *Fracture*, uneven. *Transparency*, translucent to transparent. *Tenacity*, brittle.

Production and Consumption. Cryolite is produced at only one locality in the world, at Ivigtut in South Greenland. The mine is owned by Denmark and the concession for its operation is the property of a company operating from Copenhagen. Gibbs⁴ reports that the production is divided between the Pennsylvania Salt Manufacturing Co. of Philadelphia, which has the North American rights, and a Danish firm that controls sales for the rest of the world. A majority of the production is imported by the United States. A portion, generally less than 10 per cent of the total imports, is shipped to Canada. Imports for recent years, which may serve as an approximate guide to the magnitude of the industry, are shown in the table on page 173.

Occurrence, Mining, and Milling. The Greenland deposit lies directly on the shore in an area underlain with gneisses and granitic rocks believed to be of Pre-Cambrian age. The rock immediately adjacent to the cryolite concentration is a porphorite granite. The cryolite appears to be a pegmatitic differentiation in the granite. Other occurrences, all of scientific interest only, are found in a similar geologic environment. The deposit is operated by means of an open

quarry 500 ft long. The quarry face is drilled with air drills and then shot with black powder to avoid excessive fines. The broken rock is sorted by hand. The rock is wet with water, which has nearly the same index of refraction as cryolite, thereby changing its appearance so that it can be distinguished easily from associated quartz. The selected ore is stock-piled for shipment. An extraordinary variety of minerals is found associated with the cryolite, as is common in pegmatite formations. The cryolite is closely associated with fluorite, siderite, pyrite, chalcopyrite, galena, topaz, and sphalerite. A number of rare fluorine minerals are also present. As far as feasible the noncryolite minerals are removed from the shipping ore before loading.

IMPORTS OF CRYOLITE IN THE UNITED STATES

Year	Long tons	Value	Average value per ton
1939	10,210	\$ 712,096	\$69.70
1940	25,858	1,329,788	51.40
1941	26,684	1,462,725	54.80
1942	64,565	3,859,875	59.80
1943	44,400	3,117,888	70.20
1944	15,680	1,155,787	73.70
1945	17,952	1,349,678	75.10
1946	10,200	815,627	79.80
1947	19,650	1,564,380	79.60
1948	2,101	210,050	99.97

According to Gibbs, methods of concentration of cryolite in the United States are as follows:

Due to the variety of impurities in the ore, several methods of purification have been developed. First the crude ore is screened to get rid of the very fine material in which the iron has oxidized and permanently discolored the cryolite. Then hand picking removes the fluorspar, topaz, and as much of the siderite as is free. The next stage is crushing all through $\frac{1}{4}$ -in. mesh, after which the mineral is passed on continuous rubber belts under high-power magnets which remove the magnetic impurities, including siderite and part of the pyrite. Following the magnets the ore is separated into two sizes (the coarser of which passes over two types of jigs) to remove galena and pyrite in the first and silica, hagemannite, thompsonite, and other minerals in the second. The finer sizes pass over Wilfley tables and then over jigs for removal of silica, etc. After drying and further magnetic treatment, the two sizes are remixed and ground with porcelain balls in a porcelain-lined mill. An air-separator system ensures a fineness in the finished product of at least 99 per cent through 150 mesh and 90 per cent through 300 mesh.⁴

Cryolite has been produced in the United States in small quantity only. The best known occurrence is in the Pikes Peak region of Colorado. Diligent search, accelerated during the war years when a shortage was feared, has failed to disclose tonnage of commercial interest.

Utilization. Cryolite was first used industrially in 1854 for the manufacture of alumina and soda in Denmark. Imports to the United States promptly followed

and by 1856 whole cargoes were being moved. The development of the Solvay and similar processes for the production of sodium carbonate dominated this field, and the markets for cryolite might have displayed drastic shrinkage if it had not been for invention of the Hall process for the production of metallic aluminum. This process utilizes a bath of fused cryolite for the electrolyte in which alumina is disassociated by electric current. It is a remarkable coincidence that at the time Hall was making his experiments in 1888 he had at his disposal one of the rarest minerals known, which was being imported at that time in tonnages little below present levels. This is the largest single consumer. In this market cryolite is encountering competition from synthetic cryolite manufactured from fluorspar. The fluorspar is converted to hydrofluoric acid by treatment with sulfuric acid. The hydrofluoric acid is neutralized with sodium carbonate and aluminum hydrate, producing a double fluoride of sodium and aluminum: cryolite. This manufactured material is said to be satisfactory in use and lower in impurities than the mineral of natural origin.

Ground cryolite is also used in enamels, glasses, and insecticides. Its high fluorine content makes it an effective insecticide. In 1946, 2,225,000 lb were utilized in the peanut belt of the south to combat the ravages of the velvet bean caterpillar, which was threatening the crop. Research work is being conducted to broaden the usefulness of cryolite to industry.

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DIAMOND

Composition. Diamond is pure carbon, although occasionally traces of other elements may be included in the crystal structure.

General Description. The diamond crystallizes in the cubic system: the most common crystal form encountered is the octahedron, followed by the rhombic

dodecahedron. Cubes are rare. Twin crystals are encountered frequently and at times are the cause of substantial loss of weight in cutting. Size varies from microscopic crystals to irregular masses weighing over 3,000 carats. The international metric carat has been standardized at 200 mg and is now in universal usage as a unit of production and sale. Cut stones are at times sold by "points." In this case 70 points is the equivalent of 0.70 carat. Gem diamonds vary enormously in color, size, perfection, and value. To qualify for gem use the stone must be transparent and free from objectionable color and impurities. Many grades of varying color and perfection are recognized in the trade. The gem diamond has been recognized as the most desirable and most popular of all precious stones. It generally is the highest priced precious stone, although at times exceptional specimens of ruby and emerald have been sold at higher figures.

The importance of the diamond as a gem is being overshadowed by its rise as an industrial mineral. Diamonds of nongem grade are employed in many industrial uses where the superior hardness of the mineral is of value. Fine industrials are stones of poor color but otherwise similar to gem quality. Bort, or boart, is nongem grade material, badly flawed or filled with inclusions. It is the most useful industrial form of diamond and is used extensively for the manufacture of drills and abrasives. Ballas, a spherical intergrowth of small diamond crystals, is strong and not easily shattered and therefore suitable for many industrial uses. Production is limited to Brazil and the Jagersfontein mine in South Africa. Carbonado, or black diamond, is obtained in Brazil. It is very compact and tough. It is nearly opaque and varies in color from gray to black.

Physical Properties. *Hardness*, 10, the hardest material known. The gap in hardness between 10 and 9 is believed to be greater than the gap between 9 and 1. Diamond, therefore, stands alone with regard to this property. *Hardness* varies with direction and is most pronounced on the octohedral face. *Specific gravity*, 3.145 to 3.518; carbonado, 3.15 to 3.29. *Melting point*, probably above 3000°C. *Color dispersion*, very high, 0.063, hence the play of color in the gem. *Index of refraction*, 2.4175. *Color*, in gems, colorless or faint shades of blue, brown, or yellow, rarely in clear, highly prized green, blue, orange, and red shades; in carbonado, black, dark brown, or dark gray; in bort, yellow-brown to black. *Streak*, white. *Luster*, on uncut crystal faces, greasy adamantine; on cut faces typical adamantine, very brilliant; in carbonado, dull. *Cleavage*, in crystal, highly perfect octohedral; in carbonado, none. *Tenacity*, brittle in crystallized varieties; carbonado, tough. *Solubility*, insoluble in acids. *Transparency*, transparent to X-rays, lead-glass imitations are not. In fine powder may be burned, producing carbon dioxide. It is the least compressible of all known substances.

Occurrence. The unusual properties of the diamond were first appreciated in India and production was started there, possibly over 2,000 years ago. Borneo was also an early producer. Spectacularly large stones of historical importance are all believed to be of Indian origin. Diamonds have been found in three areas either in placer deposits or associated with a conglomerate, never in place in the original rock in which they were formed. Much of the trade in the stones has been carried on in the market town of Golconda with which the diamond trade has long been associated. Present production from India and Borneo is negligible.

The first major shift in diamond production was to Brazil, then a Portuguese colony, where gems were discovered in 1721. The province of Bahia and Minas Geraes became the most important producers. Production was from placers operated with crude equipment, and the mother lode has never been discovered. It is estimated that over 15 million carats of rough stones came from the mines, which made a substantial addition to the diamond store of the world. Output declined to a trifling figure in the 1930's, but subsequently rose under the impetus of increasing demands for industrial stones occasioned by the war to an appreciable figure as shown in Table 1. No information exists concerning the reserves for future use, due to the irregular distribution of the diamonds in the alluvial sands in which they are found.

Diamonds were discovered in Africa in 1867. The first finds were in alluvial deposits, and the Orange and Vaal rivers in South Africa were soon scenes of active prospecting by thousands of men. Later, diamonds were found in a number of places remote from the rivers, and finally Kimberly was located. This was a deposit of diamonds in the original volcanic rock in which they were formed. This rock, a variety of peridotite, occurs in funnel-shaped structures, roughly elliptical in cross section and continuing to unknown depths. They are known as diamond pipes. At first they were worked from the surface by a large number of operators working small claims. This led to disorder and impossible working conditions, which were finally removed by the consolidation of the entire property under one management. Surface workings were abandoned and an orderly plan for underground operation installed. Further exploration resulted in the discovery of other diamond-bearing pipes. The occurrence of diamonds in these large ore bodies, amenable to modern methods of mining and concentration, has permitted the diamond industry to become the only gem-stone producing activity carried on in a systematic, well-organized, and regular manner.

Further exploration disclosed that diamonds were present in many areas in Africa, as shown in Table 1. The continent now supplies from 95 to 98 per cent of the world's total by weight. Belgian Congo is the largest producer and accounts for 60 to 70 per cent of the total by weight, but generally about 10 to 13 per cent of the value, since the bulk of the production consists of industrial stones of low value. Two major areas are productive. The western area is located in the south central part of the colony around Tshikapa. It is continuous with the Angolan diamond field, which it adjoins. The average grade of the deposits is less than 1 carat per cubic yard. This area is the chief source of cuttable material in the Congo, and as much as 60 per cent of the production may be so classed. Only a small part is suitable for fine gems. Over 35 widely scattered operations are active. The eastern area is small and extends for a few miles along the Bushimaie River above its junction with the Sankuru. It is the world's largest producer by weight and the lowest cost producer. Less than 5 per cent can qualify as gem material; the rest is mostly crushing bort. The average grade is estimated to run from 7 to 10 carats per yard.

Tanganyika has become a producer of growing importance during the past few years. Most of the production is obtained from placers or alluvial diggings. The large mines in South Africa were closed during a number of years when cheaper production from the alluvials could satisfy the market.

Diamonds in the United States. The only known occurrence of diamond in place in peridotite is located near Murfreesboro, Pike County, Ark. This is the only location in which mining has been carried on in anything approaching a systematic manner. The rock is similar in chemical and mineralogical composition to the kimberlite peridotite of South Africa. Diamonds were first found in 1906. A successful commercial operation has never been established, although it is reported that over 10,000 diamonds have been recovered in the locality, the largest of which weighed over 40 carats. Diamonds have been found in an area 600 miles in extent stretching from Ohio to Minnesota. They occur in the glacial drift, a mixture of soil, rock fragments, sand, and boulders, much of which was transported from the north and deposited by glacial ice. It has been conjectured that the original source of the stones may have been in Canada in the Hudson Bay area. The largest diamond encountered here is said to have weighed over 21 carats. Diamonds have also been found in the Appalachian area in a district extending from West Virginia to Georgia. The best known stone was found at Manchester, Va., in 1855. It weighed over 23 carats in the rough, and cut to slightly under 12 carats. The most recent addition was reported in 1943. The stone, the "Punch" Jones diamond, weighing 34.46 carats had been found in 1928 at Petersburg, W.Va. The significance of the find had not been noted previously. The wide-spread distribution in the Appalachian states suggests more than one source. The genesis of these stones is a mystery to geologists. The most logical explanation is the possibility of the existence of peridotite rocks in the geologic past that have been destroyed by erosion and their diamond content liberated. Diamonds have been found on the Pacific coast, particularly in California, where they have been the by-product of gold mining. The stones recovered were small, the largest weighing a little over 7 carats. Microscopic diamonds have been reported to occur in meteorites.

The world production of diamonds as reported by the U.S. Bureau of Mines is shown in Table 1. Industrial stones supply 70 to 80 per cent of the total.

Mining and Milling Methods. *South Africa.* South African diamonds are produced from two sources from pipes or necks of kimberlite, or blue ground, and from alluvial or placer diggings. In 1946 the output from the alluvial workings amounted to 256,768 carats, or 20 per cent of the total production of the Union of South Africa.

Mining Kimberlite Pipes. The kimberlite pipes were formerly all worked by open-pit, but now some of the largest mines are worked by underground methods. The walls of the pipes are nearly vertical and do not stand well, so that the depth of open-pit workings is limited by the ability to hold the walls. This may be assisted by leaving a skin of diamondiferous ground standing against the walls or by terracing back the rim of the pit.

Open-pit mining is carried on in benches, which are usually 40 to 60 ft high, but at the Premier mine, they are as high as 100 ft. Drilling and blasting are usually done on a large scale, using deep, chambered holes, and breaking 5 or 6 tons of ground per pound of dynamite. Light drills are used for the secondary breaking of large lumps. Nearly all loading is done by hand. The ore is hoisted either in tubs running on fixed trolley lines up over the edge of the pit or by haulage up

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an incline either within the pit or wholly or partly cut in the wall rock. The deepest open workings are considerably over 1,000 ft deep.

Underground mining is faced with the following chief difficulties: the instability of the walls; the pressure of the superincumbent debris in the open pits above; the necessity of the cheap handling of ore and the consequent large scale of production; the influx of mud and other debris from above mixing with the ore, making mining dangerous and increasing drainage difficulties; and the maintenance of adequate ventilation. Mining methods have been gradually evolved to meet these difficulties.

TABLE 1. WORLD PRODUCTION OF DIAMONDS, 1942 TO 1946, BY COUNTRIES, METRIC CARATS
(Including industrial diamonds)

Country	1942	1943	1944	1945	1946
Africa:					
Angola.....	791,853	794,990	799,120	803,887	808,000*
Belgian Congo.....	6,018,236	4,881,639	7,533,365	10,386,000	6,033,452
French Equatorial Africa.....	46,345	56,183	60,000	82,849	87,381
French West Africa...	49,866	36,193	69,726	79,802	51,834
Gold Coast †.....	1,055,735	1,317,798	1,165,858	812,451	830,000
Sierra Leone.....	1,046,187	834,492	608,744	504,309	559,229
South-West Africa....	56,420	94,427	154,379	152,629	163,611
Tanganyika.....	40,327	52,998	90,667	115,666	119,446*
Union of South Africa:					
Mines.....	858	84,342	552,974	878,713	1,025,019
Alluvial.....	117,963	217,987	380,708	262,529	256,768
Total.....	118,821	302,329	933,682	1,141,242	1,281,787
Brazil*.....	300,000	275,000	301,000	275,000	325,000
British Guiana.....	22,207	18,272	13,911†	15,442	30,958
Venezuela.....	34,048	22,846	22,037	12,769	20,912
Other countries.....	6,788	6,804	12,000	2,000	1,600‡
Grand total.....	9,587,000	8,694,000	11,764,000	14,384,000	10,313,000

* Estimated.

† Exports.

‡ Partly estimated; includes India, Borneo, Australia (New South Wales), and U.S.S.R.

In general, the methods of development and mining are as follows: Two large main shafts are sunk in the country rock at a sufficient distance from the pipe to ensure safety from subsidence. One of these shafts serves as a main working shaft, and the other is used for ventilation and emergencies. Working shafts are provided with skip ways, manways, and ladder- and pipeways. Since much material must be hoisted, skips are large and high hoisting speeds are used. Heavy steel headframes with efficient, large, modern hoists are common. The Kimberley mine has the deepest shaft, which was 3,600 ft deep in 1920.

At regular vertical intervals, which may be as great as 700 ft, large main haulage tunnels are driven, connecting the working shaft with the pipe. Between

these main levels the ground is further opened by sublevels 40 to 60 ft apart vertically. On the sublevels the ore is blocked out by a regular system of drifts and crosscuts. The ore from the stopes is dropped to the sublevels and trammed to vertical, circular ore chutes connecting with the main levels. There it is drawn off into skips and hoisted.

The ore is removed in the stopes by a system of caving, beginning at the upper levels in the portions of the ore body farthest from the main shaft, and retreating downward and toward the shaft from all directions. When one level has been drawn back a safe distance from the walls, stoping is started on the level below, the working faces thus forming a series of steps. Often one or more shafts are sunk within the pipe itself for development, ventilation, and access to the sublevels, which are also usually connected by inclined manways.

Milling of Kimberlite Ore. The yellow ground that occupied the upper, oxidized zone of the pipe disintegrated easily and the diamonds present could be recovered by inspection and washing. The blue ground, mined at greater depths, is a much more stable rock. For years it was common practice to expose this material on the ground at the surface and allow it to weather slowly with frequent stirring. After months of exposure the rock would break down to the extent that the diamonds could be liberated with ease. The operation was slow and expensive, involved a large capital investment, and required constant protection from theft. It was abandoned for more modern methods of mineral preparation using mechanical crushing and concentration. Corrugated spring rolls, operating with light spring pressures, are used to crush the rock. The equipment is designed to prevent crushing and loss of any large stones, a possibility not present when the ancient method of weathering the rock was employed. The crushed material is sorted, washed free from fines, and classified into various sizes that are passed over jigs to recover the heavy minerals, including diamond. The concentrates from the jigs are passed over grease tables, a type of concentration peculiar to the diamond industry. This consists of an iron table placed at a gentle slope and provided with an oscillating movement. It is covered with a thick coat of petroleum. Due to unusual surface-tension relationships, diamond will stick tenaciously to this coating of grease, while the heavy minerals with which it is associated in the jig concentrates, mostly silicates, are swept away by the current of water passing over the tables. This device is remarkably efficient, and most of the diamonds are collected within the first 6 in. of the table. The grease is scraped off at intervals and placed in a finely perforated metal container that is submerged in boiling water. The grease melts and leaves the container as a liquid. The diamonds remain and are graded according to size and quality.

Alluvial or placer mining may be carried on with the simplest equipment, little more than a pan and shovel being necessary. The techniques of prospecting and production are similar to those employed for thousands of years in gold mining. The diamond with its high specific gravity is found with other heavy minerals such as magnetite, corundum, zircon, and garnet. These minerals serve as a clue to the presence of diamond. Stream gravels, bench deposits, and conglomerates are worked with equipment derived in principle from types long established in gold recovery. The use of large dredges, representing a huge

capital investment, has not been considered feasible, in part due to the small size and undependable behavior of the diamond-bearing ground, and also to the prevalence of cheap labor in the producing areas.

Mining and Milling in Belgian Congo. Due to the abundance of native labor, hand methods are employed extensively. Trenches and pits are used in exploration and to determine the diamond content of the ground. If satisfactory the area is cleared of brush and trees. The overburden is removed and the diamond-bearing gravel shoveled into wheelbarrows or mine cars and taken to a central treating plant. One power shovel is employed in the eastern area. Great care is taken at bedrock to recover all the gravel, since the greatest concentration of values occurs at this point. Central plants are located at Tshikapa in the west and Bakwanga in the eastern area. The process of treatment is similar to that followed at Kimberly. The mill feed is screened, jigged, treated by magnetic separators, tabled to recover very small stones, and finally passed over a grease table. Precautions are taken at all points to prevent loss.

Utilization. The use of the diamond as an ornamental stone is so universal that it requires no explanation. Because of its high value and universal appreciation it is used at times as portable wealth when more bulky objects could not be concealed or transported. Its importance as an industrial mineral has increased steadily during the past decade. Imports in the United States, as reported by the U.S. Bureau of Mines, are given in Table 2.

TABLE 2. INDUSTRIAL DIAMONDS (GLAZIERS', ENGRAVERS', AND MINERS') IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1943 TO 1948

Year	Carats	Value	
		Total	Average
1943	12,084,133	\$21,890,568	\$1.81
1944	12,614,507	22,861,401	1.81
1945	10,729,869	12,810,932	1.19
1946	4,625,282	14,247,536	3.09
1947	3,999,119	13,312,668	3.33
1948	10,418,316	32,521,501	3.12

Diamond tools have made possible the fast and precise machining of metals. They are indispensable in the automobile and aircraft industries. The designing of tools and the proper orientation of the diamond edge have become a science employing a knowledge of crystallographic and directional hardness in the stone. A large variety of tools are employed for many uses. Diamonds are also used for dies for the drawing of fine wire such as the tungsten filaments in universal use in electric lights. Such dies possess the desirable property of not changing diameter in use due to the superior hardness of the material. They are used similarly to supply an orifice of unchanging dimension in oil burners. Abrasive wheels charged with diamond dust are used extensively by lapidaries in the cutting of semiprecious stones. The diamond drill has become one of the most valuable

exploration tools at the disposal of the geologist. By its use a core of rock, representing hundreds or thousands of feet of depth, may be extracted from the earth for inspection as to its identity and structure or for analysis to determine value. The mining industry has become interested in the use of the diamond drill for stoping ore, the actual drilling of the hole that contains the explosive for blasting the ore loose from the surrounding rock. Successful and economic operation of the diamond drill in this field is now recognized. The industrial diamond, unlike the gem, wears out in use and conservation in the use of this rare mineral is therefore desirable.

The Manufactured Diamond. The diamond has never been produced in commercial quantity, although many attempts have been made. Many investigators doubt that the diamond has ever been made artificially in any form, not even the microscopic crystals that have been reported as the end product of various processes. When it is realized that the lowest priced industrial diamond sells for around \$3 per carat, or \$6,795 a pound, it is apparent that the problem is one to challenge the interest of scientific research.

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DIASPORE

Composition. Diaspore is hydrous aluminum oxide, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$: Al_2O_3 , 85.1 per cent; H_2O , 14.9 per cent.

General Description. When diaspore is found in crystallized form, it occurs in thin, flattened prisms; as foliated masses or thin scales; white, grayish, brownish, pinkish, or yellowish in color. But in the only known deposits of commercial size it occurs in an earthy or granular, sometimes pisolitic, form in clay and is gray, brown, or red in color.

Physical Properties. *Hardness*, 6.5 to 7. *Specific gravity*, 3.3 to 3.5. *Melting point*, on heating reduces to Al_2O_3 , which, when pure, melts at 1880 to 2050°C. *Index of refraction*, 1.702 to 1.750. *Color*, white, gray, brown, yellowish, pink; sometimes red from iron oxide. *Streak*, white (when pure). *Luster*, pearly to vitreous in crystals; earthy and dull when granular. *Cleavage*, platy in crystals. *Fracture*, irregular in granular type. *Transparency*, transparent to opaque. *Tenacity*, brittle.

Occurrence. Until recent years diaspore has been of mineralogical interest only, for no deposits large enough to be of commercial importance were known. It has usually been found associated with corundum and emery in dolomite and granular limestone or crystalline schists. At Chester, Mass., it occurred in large plates associated with emery.

Its most important occurrence is in clays, where its presence causes a high alumina content, at times over 70 per cent. Such clays are found in Missouri and Pennsylvania.

Some years ago it was found that important deposits of diaspore mixed with flint clay and some plastic bond clay occur in Missouri, principally along the Chicago, Rock Island, and Pacific Railway from Gerard west to Belle, with a few smaller deposits near Hofflins on the St. Louis-San Francisco line. For many years beds or pockets of flint clays have been worked commercially in these districts, but the presence of diaspore had not been recognized. Flint clay containing diaspore has a rough sandy texture and when present in the ordinary flint clay causes blistering and distortion when fired. This rough clay has thus been regarded as worthless or even detrimental, and large bodies of it were left in

abandoned clay pits, where it frequently occurred as a core near the center of the deposit or as rounded boulders in the overlying weathered clay.

This diaspora clay has been described by the Missouri Bureau of Geology and Mines as follows:

In texture, diaspora clay ranges from a compact, hard, blue or gray flint clay with scattered flecks of white or bluish white and an occasional minute oölite through a true oölitic form to a rough, porous, ash-colored mass not unlike the light-colored varieties of bauxite. Red varieties of the clay are also found. It had been discovered that where this type of clay was found there was an enrichment of alumina, depletion of silica, and frequently a very low lime and magnesia content. An analysis made on a sample of the clay by W. E. Oyler, Missouri Geological Survey, Rolla, Mo., showed the following results:

ANALYSIS OF DIASPORE CLAY FROM MISSOURI

	<i>Per Cent</i>
Moisture.....	0.60
Loss of ignition.....	14.00
Silica (SiO ₂).....	9.30
Alumina (Al ₂ O ₃).....	73.73
Iron oxide (Fe ₂ O ₃).....	0.57
Soda (Na ₂ O).....	2.00
Potash (K ₂ O).....	0.52
	<hr/> 100.72

The diaspora clay is, therefore, quite distinct from the flint clay in both texture and composition. It is apparently made up from particles and oölites of the mineral diaspora (AlO, OH) containing 85 per cent aluminum and 15 per cent water, interbedded in more or less flint clay. This composition gives rise to the name "diaspora clay," tentatively used here.*

Flint clay has been known in this north-central Ozark district since 1872. The first shipments of diaspora clay were reported in 1918.

Clays with a high alumina content due to the presence of alumina have been produced in Pennsylvania for years. They have been used in the manufacture of bricks of specified alumina content suitable for refractory use. Clays with a content of Fe₂O₃ of less than 3 per cent are used in this industry. The largest known tonnage is in Clearfield County in the Curwensville and Morgan Run areas. The tonnage of reserves for future use is not known with accuracy but is believed to be a matter of many millions of tons of clay with a content of Al₂O₃ varying from 35 to 70 per cent. Interest in these clays as a potential source of alumina for the production of aluminum metal has resulted in an expansion of knowledge with regard to their occurrence and properties.

Analyses of these clays are given in the table² on page 184.

Production. In Missouri the diaspora clay is found associated with flint clay in sink hole deposits. These are discovered by surface prospecting. At times the observance of "float," detached pieces at the surface or in stream valleys, has led to discoveries. Commonly the ground is drilled with an auger, and samples recovered at frequent intervals from the surface. After location of a promising

* Missouri Bureau Geology and Mines, *Biennial Report*, pp. 17-20, State Geologist, Fiftieth General Assembly, 1919.

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area, it is stripped of overburden with scrapers or bulldozers, exposing the desired strata. Generally, this is operated as a quarry. A face is developed, behind which blasting holes are drilled for breaking with black powder or dynamite. The broken clay is sorted by type and piled for shipment. In Pennsylvania the position of the clay horizons is such that underground mining is of increasing importance. The tonnage of diasporite produced is not known, since its identity is lost in the clays in which it is contained.

ANALYSIS OF DIASPORE CLAYS

Type of clay	Per cent by weight							
	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O + K ₂ O	Ignition loss
Burnt nodule.....	75.72	4.00	2.17	2.75	0.10	0.25	0.38	14.40
Pine-grained nodule.	61.52	.....	.....	.....	.....	.....	.....	13.88
Green nodule.....	54.50	26.76	0.80	2.26	0.18	0.30	0.95	13.50
Nodule, block.....	49.44	.....	.....	.....	.....	.....	.....	13.46
Flint.....	38.37	43.74	1.29	1.72	0.04	0.28	0.96	13.16
Block.....	37.55	43.40	1.06	1.77	0.13	0.43	1.51	13.40
Semiflint.....	35.13	46.76	1.52	1.57	0.18	0.73	2.60	11.17
Slabby, soft.....	30.79	52.62	1.63	1.27	0.30	0.75	3.21	8.76
Plastic, soft.....	27.40	56.84	1.82	1.28	0.30	0.91	2.99	8.09

Utilization. The principal use is in the manufacture of brick for employment in processes of high temperature. Refractoriness increases with Al₂O₃ content. This is the largest tonnage consumer. Small quantities have been calcined and used as an abrasive. The shortage of bauxite during the war resulted in a program of research applied to diasporite clays with the intention of producing Al₂O₃ for reduction to metallic aluminum. The process worked out by the U.S. Bureau of Mines involved the sintering of the clay with limestone and soda ash, thereby converting the alumina into a form soluble in water and leaving the silica in insoluble form. Carbonation of the purified solution with CO₂—air mixture or scrubbed flue gases precipitated Al₂O₃·3H₂O. This is easily converted to Al₂O₃ by calcination, producing a product of sufficient purity to qualify as a raw material for reduction to aluminum. The process is not in a position to compete economically with abundant bauxite, but may become more important as bauxite reserves suffer further depletion.

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DIATOMITE OR DIATOMACEOUS EARTH

Composition. Diatomaceous earth (also known as infusorial earth, kieselguhr, fossil flour, fossil meal, tripolite, diatomite, polirschiefer, desmid earth, molera, white peat, tellurine, randanite, ceysatite, bergmehl, radiolarian earth, by the

TABLE 1. ANALYSES OF DIATOMACEOUS EARTH

	1	2	3	4	5	6	7	8
Silica (SiO_2).....	80.53	80.66	81.53	75.68	88.78	86.92	72.50	86.89
Alumina (Al_2O_3).....	5.89	3.84	3.43	9.88	2.68	4.27	11.71	2.32
Iron oxide (Fe_2O_3).....	1.03	.....	3.34	2.92	Trace	.....	2.35	1.28
Lime (CaO).....	0.35	0.58	2.61	0.29	1.61	1.60	0.32	0.43
Magnesia (MgO}).....	.....	.....	.....	0.69	1.30	Trace	0.83	Trace
Potash (K_2O}).....	.....	.....	1.16	0.02	.....	2.48	1.88	3.58
Soda (Na_2O}).....	.....	.....	1.43	0.08	.....	.....	.....	.....
Water (H_2O).....	12.03*	14.01*	6.04*	.....	5.54	5.13	9.54	4.89
Nitrogenous matter and moisture.....	.....	.....	.....	9.21	0.10†	.....	.....	.....
	99.83	99.09	99.54	98.77	100.01	100.40	99.13	99.39

* Water and organic matter.

† Titanium oxide (TiO_2).

1. Lake Umbagog, N.H.

2. Morris County, N.J.

3. Pope's Creek, Md.

NOTE: The above three analyses are quoted from G. P. Merrill, "The Non-metallic Minerals," 2d ed., p. 72, John Wiley & Sons, Inc., 1910.

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7. Soft diatomaceous shale, Orcutt, Santa Barbara County, Calif. W. T. Schaller, Analyst, 1908.

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trade names "Sil-O-Cel" and "Filter-Cel," etc., and, erroneously, tripoli*) is a hydrous or opalescent form of silica. The amount of water of composition seems to be variable, but usually is between 5 and 10 per cent. In its natural state

* See p. 561.

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diatomaceous earth also usually contains 25 to 40 per cent of mechanically held water, which is expelled at 100°C. It usually contains some clay and certain types are high in lime. Fresh-water deposits often contain organic matter that imparts a dark-brown or almost black color to the diatomite.

The analyses in Table 1, with one change (No. 5), are quoted by Phalen.*

General Description. Diatomaceous earth occurs as a light-colored, lightweight, finely granular porous aggregate varying in texture from loosely coherent to compact. When pure and dry, its apparent specific gravity is less than 1, that is, it will float on water until saturated. It is composed of the siliceous remains of exceedingly minute aquatic organisms, known as diatoms, radiolaria, etc. These organisms are exceedingly minute and are usually so small that they can be distinguished only by the aid of a high-power microscope. Several thousand varieties of diatoms have been recognized. They are always present and, under a high-power microscope, are an absolute means of identification.

Physical Properties. *Hardness*, 1 to 1.5. *Specific gravity*, true is 2.1 to 2.2; apparent, pure dry blocks, 0.45; apparent, pure dry powder, loosely packed, 0.13. *Melting point*, 1610 to 1750°C. *Index of refraction*, 1.44 to 1.46 (variable). *Color*, pure white, cream, and pinkish to reddish, brownish, and gray when impure. *Streak*, white. *Luster*, dull and earthy. *Cleavage*, none. *Fracture*, pulverulent, to subconchoidal or irregular when compact. *Transparency*, opaque. *Tenacity*, crumbly to brittle. *Insoluble* in acids (except hydrofluoric), but easily soluble in alkalies.

Thermal conductivity, in gram-calorie-seconds, varies from 0.000227 (for dried block of apparent density of 0.53) at 200°C to 0.000315 at 800°C; and from 0.000127 (for loosely packed pulverized earth of apparent density of 0.12) at 200°C to 0.000397 at 800°C.

Occurrence. Diatomaceous earth is formed in bedded deposits on the bottoms of bodies of either fresh or salt water. Minute organisms secrete silica much as mollusks secrete lime, and thus build up their shells. When the organisms die, the organic matter largely disappears, and their shells gradually build up beds. This process is now going on in some places, although deposits of present commercial importance may be far above present water levels. Although it has been calculated that 1 cu in. of diatomaceous earth contains not less than 40 million independent shells, beds 2,000 ft in thickness are known. Other beds several hundred feet thick are known to cover several square miles.

United States. *California.*^{2,14} The best known and most extensively worked deposits in the United States are those in northern Santa Barbara County near Lompoc, operated by the Johns-Manville Corp. Here beds, of a known minimum thickness in places of 700 ft, cover several square miles. The beds are tilted and contain every gradation from diatomaceous earth, through compact types and diatomaceous shale, to hard black flint. The color varies from white to cream color or grayish. It is possible to remove large blocks suitable for sawing into bricks, blocks, etc. Deposits near San Pedro, Los Angeles County, are being worked by the Dicalite Division of the Great Lakes Carbon Corp.

* PHALEN, W. C., Diatomaceous (Infusorial) Earth, U.S. Bur. Mines, Monthly Reports of Investigations, March, 1920.

Deposits have been worked in other parts of Santa Barbara County, in Monterey, Shasta, Orange, and San Luis Obispo counties, and are known to exist in several other counties.

It is probable that the largest deposits in the world are in California.

Washington. In Kittitas County, between Ellensburg and Yakima, there are large deposits of pure-white diatomaceous earth, 8 to 20 ft in thickness. A second important district is about 15 miles south of Quincy, in the northwestern part of Grant County. Other districts are near Puget Sound and north of Big Lake in western-central Skagit County. Extensive beds of extremely fine-grained, soft, pure-white diatomaceous earth are reported in several localities.

Oregon.^{4,13} Along the Deschutes River, 6 miles west of Terrebonne, Deschutes County, are important deposits of high-grade diatomite, ranging from 0 to 67 ft thick, now being worked by the Dicalite Division of the Great Lakes Carbon Corp. Other deposits are known in Baker, Grant, Harney, Jefferson, Klamath, Linn, Lane, and Malheur counties.

Nevada. A deposit of very pure diatomite, hundreds of feet thick and reported to contain many millions of tons, occurs 7 miles from Clark (18 miles east of Reno). It is being worked by the Eagle-Picher Co., which built a large, modern plant here in 1947. Other deposits have been worked near Basalt; 3 miles east of Carlin; and at 8 miles northwest of Virginia City; and deposits are known at several other localities.

Other western states that have produced small amounts of diatomite in recent years are Arizona, Idaho,¹⁶ New Mexico, and Utah. Deposits are known in Nebraska, Texas, and other western states.

Eastern States. Although diatomite deposits are known in many eastern states and many efforts have been made to develop some of them commercially, no important eastern producer has ever developed. This is because, in general, eastern deposits are small, do not contain a high percentage of the most desirable types of diatoms, are contaminated with fine silt and organic matter that are very difficult to remove, and usually are saturated with water, which is expensive to drive off. Since the largest markets for diatomite are in the east and freight rates from western sources are high, the economic possibilities for eastern diatomites are very attractive if the technologic problems can be solved.

Deposits are known in nearly all the Atlantic seaboard states from Maine to Florida. Mills have been built in Florida, Maryland, New Hampshire, and perhaps other states, but none are now in operation.

In *Florida*, deposits have been worked near Eustis, Lake County, and are known to exist in Polk County.

In *Virginia*, extensive beds of diatomaceous earth mixed with clay occur near Richmond.

In *Maryland*, material similar to that from Virginia has long been mined in a small way along Lyons Creek, a branch of the Potapscow River, 5 miles west of Herring Bay. Deposits extend from Fairhaven on Herring Bay to Pope Creek on the Potomac River.

Deposits have been worked in *Maine*, in South Beddington, Washington County; in *New Hampshire*, deposits are known in Belknap, Carroll, Cheshire,

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both a laboratory and pilot-plant scale, but no flotation-process plant is in commercial operation.

The color of some diatomites may be improved by calcination with common salt.

Specifications and Tests. Diatomite has three main types of use: for heat and sound insulation (brick or powder form), as a filter aid, and as an adsorbent filler. It has also a wide variety of lesser uses. For each type of use certain physical and chemical properties are desired. For nearly all uses purity, that is, freedom from clay, silt, organic matter, pumicite, and soluble salts, is important. For filter aid⁹ the type, size, and shape of diatoms and the freedom from broken and very small diatoms are factors of great importance. It was formerly held that only diatomites of marine origin were of proper quality for use as filter aid, but it has been demonstrated that fresh-water diatoms of certain types and of proper size are also effective. Anderson¹ has discussed the suitability of diatomites as carriers in catalysts.

For insulation important properties are low thermal conductivity, low water content, low apparent density, and strong physical structure.

For abrasive and filler uses particle size must be carefully controlled, and the product must be free from grit. Pure white color is important for some filler uses, such as paper and paint, but not for others.

For filter aid the rate of flow and the clarity of the filtrate are the most important factors. Usually the higher rates of flow correspond to the poorer removal of solids and the lesser clarity of filtrate. By special processing, products can be made that will give a maximum rate of flow with a satisfactory removal of solids.

For use in concrete admixtures chemical purity, fineness, workability, and water retention are most important.

Markets and Prices. Diatomaceous earth is rarely marketed in the crude state, but it is generally made up into finished or semifinished products by the producing company. The distribution of markets is indicated by the distribution of consuming industries noted under Utilization. It should be noted that the most important markets are in the East and Middle West, while the most important deposits are in the Far West. Diatomaceous earth brick is packed in crates for shipment. The ground product is shipped in bags or barrels.

Research has played a very important part in building up markets for diatomite. Because of its many specialized applications research continues to be essential for holding present markets and expanding into new ones.

As noted before, diatomite is a very bulky, lightweight product and carries a high freight rate. Thus, prices quoted fob western mills are little indication of what the ultimate consumer in the East has to pay. Furthermore, prices usually quoted in the trade journals are for carload lots, while many consumers buy in relatively small lots; for example, the dry-cleaning trade, which uses diatomite for reclaiming cleaning fluids for reuse.

Prices of diatomaceous earth vary with origin. Crude, 98 to 100 mesh, was quoted in bulk in 1950 at \$25 per ton fob mill. High-temperature insulation material was \$40 per ton, and filtration grades were from \$20 to \$50, depending

on size and amount of preparation. Fine abrasive grades were quoted from 2 to 3 cents per pound, bags extra.

Utilization. The value of diatomaceous earth for most uses depends upon its physical structure. The hollow cells of the diatoms form dead-air spaces, the cause of the low apparent density of diatomaceous earth and the reason for its value as an insulating medium for both heat and sound. The great number and the exceedingly small size of these cells or pores cause the earth to be of great value as a filtering medium. While diatomaceous earth can hardly be classed as a refractory, it is highly fire resistant and is of value as a lightweight, fireproof structural material.

No statistics of the distribution of diatomite sales by uses is available, but the principal types of use in approximate order of present-day importance are: (1) filtration; (2) insulation; (3) fillers, abrasives, and adsorbents; (4) admixtures in concrete; and (5) miscellaneous uses.

The principal uses for diatomite are summarized below.

1. Filter aid and filtering medium for the clarifying of all types of liquids, organic and inorganic. A few of the chief applications are in the filtering of sugar solutions and syrups, beer, wine and distilled liquors, fruit juices and beverages of all types, mineral, vegetable, and animal oils, fats and waxes, varnishes and lacquers, lubricating oils, dry-cleaning fluids, water, sewage, trade wastes, and metallurgical slimes and solutions.
 - a. In pulverized form
 - b. As natural blocks
 - c. As artificially bonded blocks and special shapes
2. Heat and sound insulation
 - a. In the form of natural, sawed brick
 - b. In the form of artificial brick made from pulverized earth with clay or other binders
 - c. In the form of coarse or finely granular powder
 - d. As pipe covering
 - e. As insulating or fire-resistant cements (pulverized earth mixed with a binder)
3. As a filler, in pulverized form, in paints and varnishes, plastics, rubber, paper, phonograph records, hard rubber, insecticides, papier mâché, sealing wax, flooring compounds, linoleum, drugs and pharmaceuticals, fertilizers.
4. As an absorbent, in pulverized form, for many liquids (will absorb 150 to 200 per cent of its weight of water without changing its form). For example, it has been used as an absorbent for liquid disinfectants, which are evolved slowly, rendering them active for a long period.
5. As a mild abrasive, in pulverized form, in hand soaps and cleansing compounds, in silver and other metal polishes, in dental powder and pastes, as a friction-creating agent on safety-match heads and boxes.
6. As an admixture in concrete for improving workability, lowering excess water content, improving homogeneity, preventing segregation, and increasing watertightness.

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7. As a support and carrier for catalysts in chemical processes such as hydrogenation and the Fischer-Tropsch process.
8. As a structural material, both in natural block form and with clay and other binders, either with or without burning. Used as lightweight building block, partition and roofing tile.
9. In ceramics, to furnish silica needed in bodies and glazes.
10. As a bleaching agent. Varieties high in colloidal material used for purposes similar to uses for fuller's earth.
11. Chemical uses. Used in manufacture of sodium silicate, or "water glass"; ultramarine; fireworks; as a base for fixation of aniline and alizarin colors for pigments.
12. When pulverized and mixed with about one-third its weight of tallow or other hard grease and molded into bricks or sticks, it forms the so-called "grease bricks" used on buffing wheels.

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DIOPSIDE

Composition. Pure diopside is a calcium-magnesium pyroxene, with the theoretical formula $\text{CaMgSi}_2\text{O}_6$: CaO, 25.9 per cent; MgO, 18.5 per cent; SiO_2 , 55.6 per cent. *Hedenbergite* is the calcium-iron counterpart of diopside with the formula $\text{CaFeSi}_2\text{O}_6$. Diopside usually contains some iron and gradually grades into hedenbergite. Thus the name, diopside, is often loosely used to denote any one of the subspecies in this group. The color varies from white or nearly white for pure diopside through various shades of green to nearly black as the iron content increases. Thus, the canaanite variety of diopside is a grayish white, and that mined in Essex County, N.Y., has the following typical analysis:³ CaO 25.88 per cent; MgO, 12.44 per cent; R_2O_3 , 6.64 per cent; SiO_2 , 54.72 per cent (high silica due to associated quartz). The salite variety of hedenbergite-diopside [$\text{Ca}(\text{Mg,Fe})\text{Si}_2\text{O}_6$], found associated with wollastonite in the same area, is dark green, high in iron, and of no present commercial use.

General Description. Diopside commonly occurs in monoclinic prismatic crystals displaying a square or eight-sided cross section. Since it has an imperfect prismatic cleavage at 87 and 93 deg, it tends to break in pseudocubic granules. It generally presents a granular appearance although it may occur in massive form.

Physical Properties. *Hardness*, 5 to 6. *Specific gravity*, 3.2 to 3.3. *Color*, white, through green to nearly black, sometimes colorless, rarely blue. *Luster*, vitreous. *Translucent*. *Index of refraction*, 1.673 to 1.702.

Occurrence. The most common geologic occurrence is in contact metamorphic areas near limestone or in areas where limestones have been completely metamorphosed. Associated minerals are garnet, vesuvianite, tremolite, phlogopite, amphibole, and graphite. It occurs in quantity in Essex and St. Lawrence Counties, N.Y.; Switzerland, Sweden, and Finland; and doubtless in many other areas, particularly those containing metamorphosed Pre-Cambrian rocks.

Utilization. Until recently there were no commercial uses for diopside, but fine crystals have been collected for museum specimens and occasionally material has been cut for gem use.

Near Willsboro. Essex County. N.Y., is a large deposit of the grayish-white

DIOPSIDE

canaanite variety of diopside, associated in places with graphite and quartz, from which it can be readily separated. This material is coarsely crystallized and has a granular texture. Interest in this material has led to research to determine its commercial possibilities. As reported by Amberg^{1,2} it behaves in ceramic bodies like talc, having a short firing range typical of alkaline earth silicates. It is reported by the owners of the deposit (oral communication) that several interesting applications have been developed but no information on them has yet been released. So far there has been no important commercial production.

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DOLOMITE

Composition. Dolomite, calcium-magnesium carbonate, also known as pearl spar and magnesian limestone, $\text{CaCO}_3 \cdot \text{MgCO}_3$, contains theoretically CaO , 30.4 per cent; MgO , 21.9 per cent; CO_2 , 47.7 per cent (or CaCO_3 , 54.2 per cent; and MgCO_3 , 45.8 per cent). It often contains iron, manganese, silica, and other impurities. In massive form it frequently grades into ordinary limestone, and less often into magnesite.

General Description. Dolomite most frequently occurs as a massive, finely to coarsely granular rock, gray, white, or bluish in color, resembling limestone. In metamorphic form it occurs as dolomitic marble. It crystallizes in small rhombohedral crystals, often with curved faces, usually white, pink, or yellow in color.

Physical Properties. *Hardness*, 3.5 to 4. *Specific gravity*, 2.8 to 2.9. *Melting point*, does not melt; at 2700 to 3100°F is reduced to $\text{CaO} + \text{MgO}$.* *Index of refraction*, when pure, 1.500 to 1.681; iron content increases index. *Color*, white, pink, gray, brown, or black. *Streak*, white. *Luster*, in crystals vitreous or pearly; in finely granular, dull or earthy. *Cleavage*, in crystals good rhombohedral. *Fracture*, in massive form, rough to nearly conchoidal. *Transparency*, translucent to opaque. *Tenacity*, rather brittle. *Solubility*, usually slight in cold dilute acids, but good in hot acid.

* This reaction may take place at any temperature above 900°C (1652°F), but traces of CO_2 remain.

Occurrence. Dolomite is widely distributed in large quantities both geologically and geographically. It occurs usually, in the largest deposits, in bedded formation with other sedimentaries, often associated with limestone or, less commonly, with magnesite. The modes of formation are (1) by deposition from a solution of mixed carbonates of calcium and magnesium in carbonated waters; (2) by replacement of a part of the calcium carbonate of calcite or limestone by solutions containing MgCO_3 ; (3) by solution of a part of the CaCO_3 in magnesian limestones in preference to the less soluble MgCO_3 , thus increasing the proportion of MgCO_3 .

Metamorphosed dolomites form some of the commercial marbles. Many of the marbles of Vermont, Georgia, and Tennessee contain sufficient MgCO_3 to be classed as dolomitic marbles. These marbles are less soluble than the pure calcite marbles and are sometimes preferred, for that reason, for structural purposes.

TABLE 1. DOLOMITE AND DOLOMITIC LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES FOR SPECIFIED PURPOSES

	1942	1943	1945	1946
Dolomite for:				
Basic MgCO_3 :*				
Short tons.....	117,650	203,240*	295,540	294,360
Value.....	\$151,756	\$242,974*	\$373,919	\$464,750
Magnesium metal:				
Short tons.....	†	887,830	†	
Value.....	†	\$891,350	†	
Refractory uses:				
Short tons.....	1,354,090	1,105,560	1,027,090	1,035,110
Value.....	\$1,197,386	\$1,120,258	\$1,120,136	\$1,146,864
Dolomitic lime for:				
Refractory (dead-burned dolomite):				
Short tons.....	1,229,357	1,276,725	1,187,330	1,077,980
Value.....	\$10,817,634	\$11,243,017	\$10,613,711	\$10,101,707
Paper mills:				
Short tons.....	85,000	72,000	52,000	35,000
Value.....	\$604,000	\$524,000	\$413,000	\$323,000
Total (calculated as raw stone).....	4,100,000	4,900,000	3,801,000	3,555,000

* Includes refractory magnesia, except for 1942.

† Figures not available.

Geographically, deposits of dolomite are so widely distributed and of such common occurrence in nearly all countries that it is not worth while to attempt to list even the producing localities. Dolomite is generally considered as a limestone for most purposes. Some of the more important dolomite districts of the United States have been listed by Weitz.¹³

DOLOMITE

Production. Statistics of United States production of dolomite and its primary products, where used as sources of magnesium compounds, are shown in Tables 1 and 2.

TABLE 2. SPECIFIED MAGNESIUM COMPOUNDS PRODUCED, SOLD, AND USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946

Product	Plants	Produced, short tons	Sold ^a		Used, short tons
			Short tons	Value	
1945					
Specified magnesias (basis 100% MgO) and Mg(OH) ₂ , USP and technical:					
Extra-light and light magnesias.....	5	1,127	1,196	\$488,570	
Heavy magnesia and Mg(OH) ₂	3	1,084	869	251,208	^b
Total.....	5 ^c	2,211 ^d	2,065	739,778	^b
Precipitated MgCO ₃	11	50,205	8,469	812,791	41,794
MgCl ₂ , 100 per cent basis.....	5	121,475	^e	^e	104,081
MgSO ₄ , 100 per cent basis.....	3	27,610	27,142	1,377,311	
1946					
Specified magnesias (basis 100% MgO) and Mg(OH) ₂ , USP and technical:					
Extra-light and light magnesias.....	6	1,967	1,926	808,240	
Heavy magnesia and Mg(OH) ₂	4	1,874	1,620	416,775	^b
Total.....	6 ^c	3,841 ^d	3,546	1,225,015	^b
Precipitated MgCO ₃	11	47,423	8,805	876,306	38,495
MgCl ₂ , 100 per cent basis.....	3	32,137	^e	^e	^e
MgSO ₄ , 100 per cent basis.....	2	^e	^e	^e	

^a Sales by a producer to an affiliated consumer for immediate use are not included under "Sold" but are under "Used."

^b Magnesium and Mg(OH)₂ used by producing firms in making other magnesias are not shown.

^c A plant producing more than one grade or product is counted but once in arriving at total.

^d Exclusive of magnesia made from Mg(OH)₂, to avoid duplication.

^e Bureau of Mines not at liberty to publish figures.

Statistics of world production of dolomite for these uses are not available, but it is well known that most of the industrialized countries use dolomite in the same ways that it is used in this country.

Since deposits of dolomite are so widespread geographically and since it is such a low-priced commodity, it follows that centers of production are close to markets. The markets for dolomite refractories are chiefly in the large iron- and steel-producing districts, such as Pittsburgh and Bethlehem, Pa.; Cleveland, Canton, and Youngstown, Ohio; Gary, Ind.; and Birmingham, Ala.

Basic magnesium carbonate is made chiefly at the plants of the companies who make the finished insulating products. These once were largely concentrated in

Pennsylvania, but in recent years plants have been built in California and other parts of the country.

Utilization. Dolomite is used for many of the purposes for which limestone is used. Often little distinction is made between limestone and dolomite, and both are often sold under the name of limestone. Since dolomite grades into limestone by imperceptible degrees, passing from a pure dolomite through high- and low-magnesian limestones to pure limestone, this lack of careful distinction is often justifiable. Some of the uses for which both dolomite and limestone are produced are given below. (For further information concerning these uses see Limestone and Stone.)

Uses Common to Limestone and Dolomite.

1. As a flux, used in smelting iron, steel, ferroalloys, and so on
2. In the manufacture of lime. Dolomite used for high-magnesian limes
3. Agricultural limestone
4. As crushed stone, riprap, and rubble
5. As building stone (use of dolomite limited, except as dolomitic marble)
6. In finely pulverized form, as a substitute for chalk whiting, used in putty, paint, rubber and so on; dolomite used less than pure limestone, calcite, or marble
7. As terrazzo, stucco dash, concrete block facings, and so on
8. For making mineral wool
9. Source of metallic magnesium

The most important uses for dolomite, for which limestone cannot be substituted, are in the manufacture of dead-burned dolomite refractories and in the preparation of basic magnesium carbonate, which is used with asbestos in making "85 per cent magnesia" heat-insulating material. It has also been used in the manufacture of epsom salts (see Epsomite).

During the Second World War dolomite was an important source of metallic magnesium, but with the closing of most of the war-built plants after the war the importance of this use greatly declined.

As noted under Magnesite and Magnesium Compounds, dolomite is used extensively with other sources of magnesium, such as sea water, brucite, magnesite, and magnesium chloride from brines to make all types of magnesium products.

Dolomite Refractories. *Methods of Manufacture.* Dolomite in its natural state is not a refractory material, but by dead-burning or calcining at a high heat it may be made into a refractory. When dolomite is heated to about 950°F, carbon dioxide is driven off and most of the magnesium carbonate is changed to magnesium oxide. When the heating is continued to from 2700 to 3100°F all the moisture is driven off and all but about 0.5 per cent of the carbon dioxide. This product is called "dead-burned dolomite," and has a high refractory value. The dead-burned product made from pure dolomite has two chief disadvantages, however. (1) While the magnesia (MgO) portion of the product is stable and inert, the lime (CaO) portion is active chemically, hydrating (from contact with moisture) to Ca(OH)_2 or recarbonating to CaCO_3 (from CO_2 in the air). This

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causes the product to slake and disintegrate during storage and use. (2) The product lacks a good bond and, therefore, has a short life in the furnace.

In order to overcome these difficulties, several processes of treatment have been devised. One of these depends upon the nearly complete elimination of CaO. One method of accomplishing this is to heat the dolomite to about 950°F, which is sufficient to calcine the MgCO_3 to MgO , which may be removed in decomposed form, while the CaCO_3 is not calcined but remains in crystalline form. Another method is to calcine at a higher temperature, so that both the MgCO_3 and the CaCO_3 are reduced to the oxides. The CaO is more soluble in water than the MgO and thus, by repeated washing, the final product may contain not more than 3 to 10 per cent CaO.

The methods in more common commercial use depend upon adding to the crushed dolomite, before calcining, an impurity that will unite with the CaO and form compounds which do not slake. Such impurities, known as "dead-burning agents," must be inexpensive and of such a nature that they will not lower the melting point of the dolomite sufficiently to render it useless as a refractory.

Over the past 40 years a very large amount of research work has been done on the problem of making improved dolomite-base refractories. Many patents have been granted on such products and processes, and the literature of the subject is extensive. The patented products are sold under such trade names as "Sta-set," "Magnifer," "Syndolag," and "Magdolite." Some of these are made from mixtures of dolomite and other sources or magnesia, such as brucite and magnesite, with or without additive fluxing agents.

These refractories are generally sold in the form of grains and are used in making and repairing the bottoms and lower side walls of basic open-hearth steel furnaces. Refractory brick made solely from dead-burned dolomite has not been very satisfactory, but dolomite is one of the sources of magnesia used, with other magnesia materials, for making high-magnesia refractory brick.

Basic Magnesium Carbonate. Basic magnesium carbonate, "block magnesia" or magnesia alba, has been assigned several formulas: $4\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$, $3\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$, and $3\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$, the last being that of the natural mineral hydromagnesite. Its principal use is in the manufacture of pipe and boiler coverings and other forms of heat insulation. The well-known "85 per cent magnesia" pipe covering consists of about 85 per cent basic magnesium carbonate, usually made from dolomite, together with asbestos fiber used as a binder. The usual method for making this material is the Pattinson process, patented nearly a century ago in England. This process may be used with other sources of magnesium, such as brucite and magnesite, but dolomite is almost always used in this country.

The method of manufacture is illustrated in the flow sheet (Fig. 5) prepared by the Magnesia Association of America. It will be noted that in this process, in addition to the basic magnesium carbonate, by-products, and additional products of precipitated calcium carbonate, magnesia alba, and pure, light-calcined magnesia are obtained.

Other Uses for Dolomite. As noted under Magnesite and Magnesium Compounds, the use of dolomite as a source of magnesia or magnesium is very closely

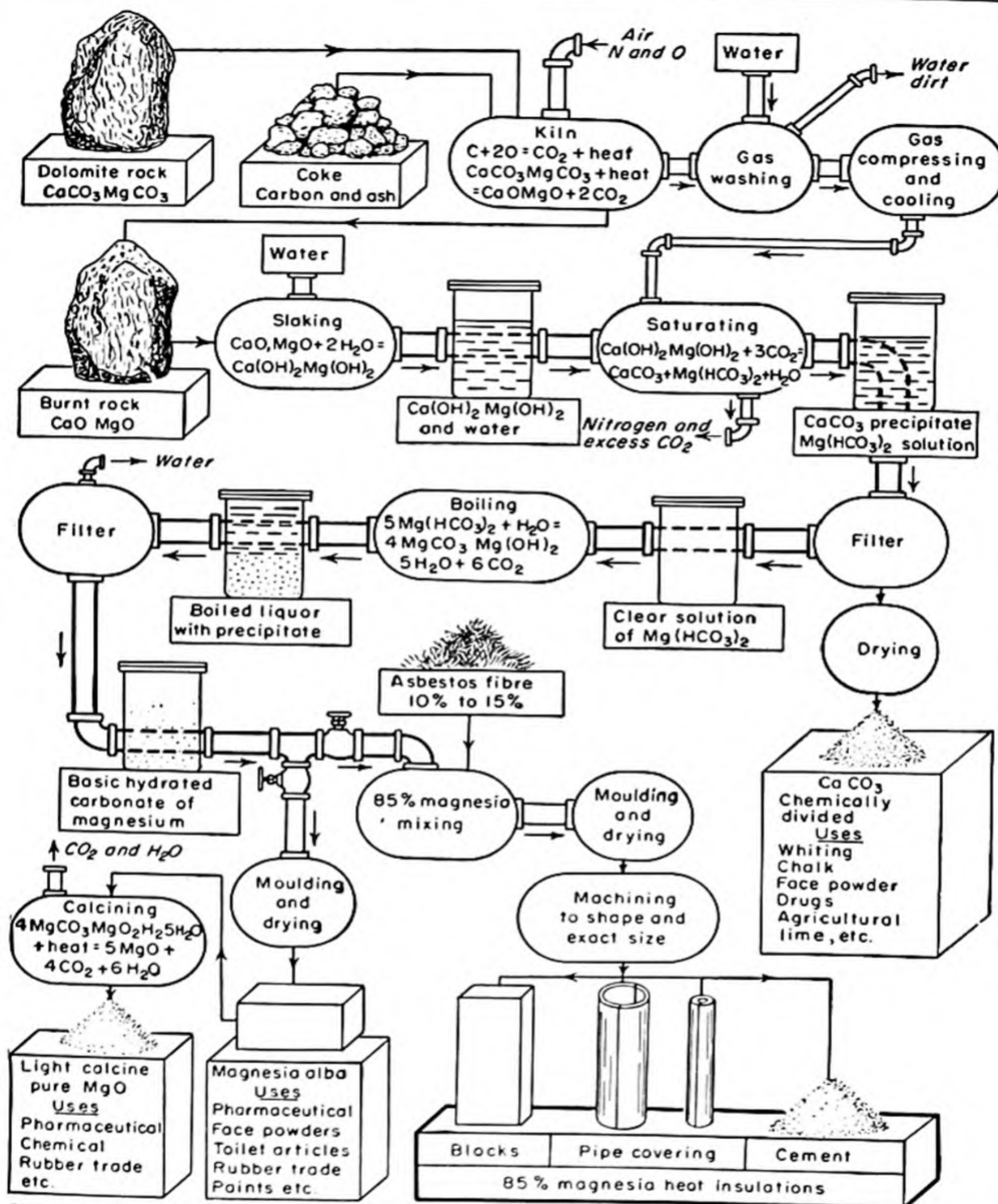


FIG. 5. Flow chart illustrating manufacture of "85 per cent magnesia." The darkened lines show the actual process involved. The lighter lines, by-processes.

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tioned in with other sources. War conditions gave a great stimulus to the increased use of dolomite in both old and new ways. These uses have been very well summarized by Harness and Jensen in the U.S. Bureau of Mines Yearbook, 1942, from which the following is quoted.

Dolomite has long been used as a basic refractory for open-hearth maintenance and repair, averaging five to eight times the quantity of magnesite used for refractory purposes. Only recently, however, has dolomite invaded the metal field, competing with and supplementing magnesite and brines as a source of magnesium metal and compounds.

The following outline covers methods of recovering magnesium from dolomite which were either in commercial use during 1942 or to be used in plants under construction in that year.

1. Direct reduction with ferrosilicon to magnesium metal. This process is used by New England Lime Co., Canaan, Conn.; Ford Motor Co., Dearborn, Mich.; Electro-Metallurgical Co., Spokane, Wash.; Amco Magnesium Co., Wingdale, N.Y.; Magnesium Reduction Co., Luckey, Ohio; and Permanente Metals Corp., Manteca, Calif.

2. Processes based upon the reaction $\text{Ca(OH)}_2 + \text{Mg(OH)}_2 + \text{MgCl}_2 \rightarrow \text{CaCl}_2 + 2\text{Mg(OH)}_2$. The calcium and magnesium hydroxides are obtained by slaking calcined dolomite, and the magnesium chloride is a constituent of sea water and well brines. Calcium chloride may be added to well brines and sea-water bitterns before the milk of dolomite is added, in order to precipitate sulfate ions as synthetic gypsum (calcium sulfate), which is sold as a by-product. If this preliminary step is not used, synthetic gypsum is precipitated to some extent with the magnesium hydroxide. The precaution is unnecessary with raw sea water, as the solution of salts is so dilute that any gypsum formed is redissolved. Permanente Metals Corp. (plant at Moss Landing, Calif.) and Northwest Magnesite Co. (plant at Cape May, N.J.) use the process to recover magnesia from raw sea water, the former for conversion to metal and the latter for refractory use; and The Dow Chemical Co. at Ludington, Mich. (plant not completed in 1942) and the Michigan Chemical Corporation, St. Louis, Mich., use (or will use) the method with well brines as the raw material, the former for metal use and the latter for refractory purposes.

3. Processes based upon the reaction $\text{Ca(OH)}_2 + \text{Mg(OH)}_2 + \text{CaCl}_2 + 2\text{CO}_2 \rightarrow \text{MgCl}_2 + 2\text{CaCO}_3 + 2\text{H}_2\text{O}$. The calcium and magnesium hydroxides are obtained by hydrating calcined dolomite, and in present practice the calcium chloride used is a by-product of the Solvay soda-ash process. Carbon dioxide is available from the dolomite kiln gases. There are several possible variations in the process, depending on whether the end product desired is magnesium chloride or magnesium hydroxide and also on the purity and grain size of the dolomite. If the dolomite is too fine grained it may be impracticable to recover the magnesium content as magnesium hydroxide, for the latter becomes more gelatinous and progressively harder to filter with decreasing dolomite grain size. The process is employed by the Diamond Alkali Co., Painesville, Ohio; Mathieson Alkali Works (Inc.), Lake Charles, La.; and in a pilot plant of the Bureau of Mines at Boulder City, Nev., all for conversion to metal.

4. Dolomite is calcined and washed with carbon dioxide-free water, which dissolves most of the lime, leaving magnesia undissolved. The Standard Lime & Stone Co. uses the process at its Millville, W.Va., plant, making "Sta-set" magnesia-grain refractories.

5. Milk of dolomite is carbonated, precipitating calcium carbonate, which is removed, leaving magnesium bicarbonate in solution.

a. The solution is then heated, precipitating a basic magnesium carbonate. This is the Pattinson process used by Philip Carey at Plymouth Meeting, Pa.; Ehret Magnesia Manufacturing Co., Valley Forge, Pa.; Johns-Manville Products Corp., Manville, N.J., and Waukegan, Ill.; Keasbey & Mattison Co., Amoler, Pa.; and Standard Lime & Stone Co., Millville, W.Va. Basic magnesium carbonate is used in making "85 per cent magnesia" insulation for steam boilers and pipes.

b. The solution is neutralized with hydrochloric acid, yielding magnesium chloride. This process is to be used by the International Minerals & Chemical Corp., Austin, Tex., supplementing its supply of by-product magnesium chloride from Carlsbad, N.Mex., potash brines for conversion to metal.

6. Milk of dolomite is reacted with hydrogen sulfide, thereby dissolving the calcium as calcium bisulfide and leaving a precipitate of magnesium hydroxide, which may be filtered and calcined. The method is used by the Warner Co., Devault, Pa., for making refractory magnesia.

7. Milk of dolomite is used instead of lime in the ammonia kilns in the ammonia-soda process; ammonia is driven off, leaving magnesium hydroxide and magnesium oxide in a solution of calcium chloride. The insoluble magnesium compounds are filtered off and reacted with hydrochloric acid to yield magnesium chloride for conversion to metal. The hydrochloric acid is a by-product of the magnesium metal cell. The so-called "acid process" is one used by the Diamond Alkali Co.

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EPSOMITE

Composition. Epsomite or epsom salt is magnesium sulfate, $MgSO_4 \cdot 7H_2O$: MgO , 16.3 per cent; SO_3 , 32.5 per cent; H_2O , 51.2 per cent.

General Description. Epsomite commonly occurs as white, granular, fibrous or earthy masses or in crusts; rarely in crystals. It is a common constituent of mineral waters.

Physical Properties. *Hardness*, 2 to 2.5. *Specific gravity*, 1.7 to 1.8. *Melting point*, $250^\circ C$. *Index of refraction*, 1.433 to 1.461. *Color*, colorless or white. *Streak*, white. *Luster*, vitreous or dull. *Cleavage*, perfect brachypinacoidal. *Transparency*, transparent to translucent. *Tenacity*, brittle. *Solubility*, soluble in water. *Taste*, bitter and salt.

Occurrence. Epsomite is a common constituent of ocean, salt lake, and spring waters, from which it may crystallize by evaporation. It is also formed by the action of sulfuric acid (from decomposing sulfides) on serpentine, talc, magnesite, and other magnesium rocks. At Stassfurt, Germany, it occurs in granular masses due to the alteration of kieserite ($MgSO_4 \cdot H_2O$).

Epsomite occurs in quantity in the Stassfurt salt deposits in *Germany*, and it is also produced commercially from the kieserite of these deposits. At the type locality at Epsom in Surrey, *England*, it occurs in solution in mineral waters. At Montmartre, near Paris, *France*, it occurs with gypsum.

United States. The chief and almost only sources of epsomite or of the anhydrous magnesium sulfate in the United States today are the well brines of Midland, *Michigan*. As noted below, former production in other states had practically ceased by the end of 1946.

In *Wyoming* there are several epsomite localities in Albany, Converse, Laramia, Caroon, and Natrona counties, principally in or near soda lakes. Purification plants were once operated at Medicine Bow, Albany County, and at Douglas, Converse County, but there has been no production in recent years. Most of the epsomite in these soda-lake deposits is mixed with varying amounts of mirabilite ($Na_2CO_3 \cdot 10H_2O$) or other sodium salts.

In *Washington* there are several epsomite lake deposits in northern Okanogan County, extensions of the Canadian deposits in the Osoyoos District of British Columbia. These lakes, such as Epsom Lake and Epso Lake, have coatings several inches thick on the edges and bottoms of shoals. Refining plants have been operated at Oroville and Tonasket, the latter as recently as 1942. At one time Canadian crude epsomite was also refined at Oroville.

In *Texas* calcined magnesium sulfate was produced from well brines for several years at O'Donnell, but the plant was dismantled in 1945.

At Webster, *North Carolina*, epsomite, with a small nickel by-product was produced from olivine by reaction with sulfuric acid for a few years prior to 1943. By a similar process epsomite was produced from serpentine at Augusta, *Georgia*, from 1943 to 1946.

In *California* it has been reported in Alameda, Amador, Lake, Napa, Santa Clara, and Sonoma counties; in *Colorado* at several localities in coal mines, in mineral waters, in alkali deposits, and in alkali lakes; in *New Mexico*, at Estancia Lakes, Torrance County. Epsomite is reported in limestone caves in *Kentucky*, *Tennessee*, and *Indiana*.

In *Utah* a deposit of considerable size has been reported near Manti, Sanpete County; it also occurs in Emery County. In Beaver County on the east side of Mount Baldy near Beaver, Utah, epsomite is reported as crusts and crevice fillings sometimes a foot thick.

Canada. Epsomite occurs in Canada at several localities in British Columbia, the more important of which are (1) in the Clinton Mining Division, $1\frac{1}{2}$ miles south of Clinton, in Lillooet; (2) in the Ashcroft Mining Division near Basque on the Canadian National Railway; (3) in the Osoyoos Mining Division at Spotted Lake.

At Clinton the mineral occurs as a crust on an alkaline lake about 12 acres in area. Two grades have been mined: No. 1 grade, or the purer upper crust, 4 to 6 in. thick, which is sufficiently pure to be classed as technical salts and sold as such without purification; and No. 2 grade, several feet thick, underlying No. 1, which is more or less mixed with mud and must be purified. The salts were shipped to a plant at Oroville, Wash., for purification.

Near Basque about 12 miles from Ashcroft and $3\frac{1}{2}$ miles from Hammond's Spur on the Canadian Northern Pacific Railway is a series of five lakes containing epsomite, ranging in area from 2 to 8 acres. These lakes contain very pure epsomite, 40 ft thick in places, covered with water, up to June or July, to a depth of 6 in. or 1 ft. In the summer the water on top evaporates, leaving a solid surface of hard white crystal, which is sawed in slabs and harvested like ice. When the surface layer has been removed, the saturated solution beneath evaporates and forms a new crust, which, in turn, is harvested. Some of the salt solidifies surrounded by mud rings and must be purified, but part of it (the upper crust) is sufficiently pure to be sold as technical salts.

Analysis of a sample from the upper crust showed: MgSO_4 , 44.58 per cent; H_2O , 50.84 per cent; insoluble, 0.76 per cent; other soluble salts, 3.82 per cent. Epsom salt equivalent to MgSO_4 amounted to 91.28 per cent. The lower layers must be refined, and a plant was built at Basque for this purpose.

At Spotted Lake, near Kruger Mountain, Osoyoos Division, British Columbia, a deposit of epsomite has been developed. The occurrence here is similar to those described above. The Spotted Lake deposits also extend over into the state of Washington.

Production and Consumption. The most recent United States production figures are for 1945, when there were but three producers. In 1946 there were but two producers. In 1945 total sales from domestic production of epsom salts, recalculated to 100 per cent magnesium sulfate basis, was 27,142 short tons,

valued at \$1,377,311. Since the war imports have been practically nonexistent, so domestic sales must approximate domestic consumption. For 20 years or more prior to the war we imported 4,000 to 6,000 tons of crude and refined magnesium sulfate salts per year, chiefly from Germany, but the rate of importation was tending to decline even before the war.

At one time Germany was the largest producer in the world and did a large export business. Canada has always been a small producer, in spite of her resources, due to geographic location of deposits and to limited markets. Italy was once a small producer.

Manufacture and Refining. Epsom salts of commercial grade are made in the following ways:

1. Crude salts mined and shipped as technical grade
2. Crude salts mined and refined by recrystallization
3. Technical and USP grades made as a by-product in the manufacture of common salt by evaporation
4. By recrystallization from kieserite (in Germany only)
5. By action of sulfuric acid on magnesia (MgO), magnesium hydroxide [$\text{Mg}(\text{OH})_2$], magnesite or magnesium carbonate (MgCO_3), dolomite or calcium-magnesium carbonate [$(\text{Ca},\text{Mg})\text{CO}_3$], olivine [$(\text{Mg},\text{Fe})_2\text{SiO}_4$], and serpentine ($\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_3$)
6. By crystallization from mineral waters (as at O'Donnell, Tex., and Epsom, Surrey, England)
7. By separation and crystallization from alkaline waters containing mixtures of salts (as at Douglas, Wyo.)

Epsom salts, magnesium chloride, and potash salts have been recovered from the residual bitterns left after the extraction of common salt from sea water and other brines, particularly at San Mateo, Calif. This salt has also been made from astrakanite, or bloedite ($\text{Na}_2\text{SO}_4 \cdot \text{MgSO}_4 \cdot 4\text{H}_2\text{O}$), from a deposit in Saskatchewan, Canada.

The principal source of epsom salts for many years before the war was kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) from the salt deposits at Stassfurt, Germany. The crude kieserite, which is slightly soluble in cold water, is washed with water to remove the chlorides of magnesium and sodium. The remaining powder is packed in wooden molds, where it sets to a solid cake containing 80 to 90 per cent magnesium sulfate. These cakes are broken down, dissolved in hot water, and recrystallized to epsom salts.

When dolomite or magnesite is treated with sulfuric acid, soluble magnesium sulfate is formed, leaving insoluble calcium sulfate, which is removed by filtration. The resultant liquor is concentrated by evaporation and allowed to crystallize as epsom salts.

Marketing, Grades, and Prices. Two grades of epsom salts are commonly produced and marketed: the USP grade (practically chemically pure) and the technical grade, which is at least 90 per cent pure and usually over 90 per cent. The technical grade is often produced in much coarser crystals than the USP grade. The salts are sometimes shipped in 100-lb burlap bags, but usually in wooden barrels. They are sold wholesale, at a price per 100 lb fob the principal

markets—for example, New York City. The price for the technical grade varies more than that of the USP grade, due to the wider range of purity permissible.

In 1950 technical grade sold for \$2.15 per 100-lb bag in carload lots; USP grade was quoted at \$2.35.

Utilization. The most important use for the technical grade of epsom salts is in the rayon industry, where it is used for the coagulation of cellulose solutions into filaments. Other uses are in tanning; warp sizing of cotton cloth; in loading cotton textiles; in dyeing; for weighting silk, paper, and leather; as a fertilizer ingredient; in the enameling industries; in fireproofing compounds; and in making paints and soaps. The purified or USP grade is used mostly in the drug trade as a valuable medicinal product and in the manufacture of mineral waters.

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FELDSPAR

Composition and General Description. Feldspar is the name of a group of minerals rather than of a single species. The feldspars are aluminosilicates of potassium, sodium, calcium, and rarely barium. Feldspars are found in a great variety of colors, the most common of which are white, gray, salmon, pink, brown, yellow, and green. They crystallize in the monoclinic and triclinic systems, and twinning is very common. All feldspars have a good cleavage in two directions at 90 or nearly 90 deg apart.

The composition of the principal feldspars is given in Table 1.

TABLE 1

Feldspar	Formula	Theoretical composition, per cent						Specific gravity	Hardness
		K ₂ O	Na ₂ O	CaO	BaO	Al ₂ O ₃	SiO ₂		
Orthoclase . .	K ₂ O:Al ₂ O ₃ :6SiO ₂	16.9	.....	.....	...	18.4	64.7	2.44-2.62	6
Microcline . .	K ₂ O:Al ₂ O ₃ :6SiO ₂	16.9	.....	.....	...	18.4	64.7	2.54-2.57	6-6.5
Albite	Na ₂ O:Al ₂ O ₃ :6SiO ₂	.....	11.8	.....	...	19.4	68.8	2.5-2.7	6-6.5
Anorthite . . .	CaO:Al ₂ O ₃ :2SiO ₂	.....	.....	20.1	...	36.62	43.28	2.6-2.8	6-6.5

FELDSPAR

Albite and *anorthite* constitute the two extremes of a series of complex feldspars known as the *plagioclase* feldspars. In this series the albite and anorthite molecules replace each other in varying proportions. In *oligoclase* and *andesine* the albite molecules predominate; in *labradorite* the albite and anorthite are nearly equal; in *bytownite* the anorthite molecules predominate. These feldspars are also known as the *soda-lime feldspars*.

Anorthoclase and *soda orthoclase* are mixtures, in varying proportions, of the orthoclase and albite molecules.

Celsian is a barium feldspar ($\text{BaO}:\text{Al}_2\text{O}_3:2\text{SiO}_2$).

Hyalophane, barium-potash feldspar, is a mixture, in varying proportions, of the celsian and orthoclase molecules.

Adularia is a transparent orthoclase.

Sanidine is a clear, glassy orthoclase.

Amazonstone is a green variety of microcline sometimes used as a gem stone.

Moonstone is a transparent or translucent, opalescent variety of orthoclase. This term is also sometimes applied to a translucent variety of albite.

Graphic granite is an intimate intergrowth of quartz and feldspar in which the quartz is distributed more or less uniformly throughout the feldspar mass in parallel, wedge-shaped grains. Graphic granite is normally composed of about 75 per cent feldspar and 25 per cent free quartz.

Cornish stone or *Cornwall stone* is a type of decomposed granite used extensively for ceramic purposes in England (see description below).

TABLE 2. ANALYSES OF COMMERCIAL FELDSPARS

No.	Igni- tion loss	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	BaO	K_2O	Na_2O	Total
1	....	64.67	19.18	0.20	.....	0.99	Trace	....	12.76	2.54	100.34
2	....	74.34	14.45	0.14	.....	Trace	Trace	....	8.63	2.00	99.56
3	....	67.81	18.55	0.08	.....	0.21	0.07	....	9.32	4.27	100.31
4	0.25	65.24	19.74	0.12	.....	0.00	0.00	....	11.84	3.04	100.23
5	0.40	73.88	15.73	0.36	0.01	0.86	0.36	0.00	0.48	7.97	100.05
6	0.17	65.37	17.92	0.02	Trace	0.17	Trace	0.00	13.05	2.10	98.80
7	1.00	64.92	22.28	0.21	Trace	1.60	Trace	0.00	1.10	9.20	100.31
8	0.12	64.44	17.63	0.74	Trace	0.40	0.02	0.02	13.39	3.31	100.07

No. 1. Potash feldspar, New Castle, Lincoln County, Maine.

No. 2. Pegmatite, Cathance, Sagadahoc County, Maine.

No. 3. Feldspar, Auburn, Androscoggin County, Maine.

No. 4. Feldspar, Portland, Hartford County, Conn.

No. 5. Albite pegmatite, Bedford, Westchester, N.Y.

No. 6. Plumtree mica mine, Avery County, N.C.

No. 7. Carolina Mineral Co. (albite), Mitchell County, N.C.

No. 8. Richardson mine, Bedford Township, Frontenac County, Ontario.

Of all the feldspars, only microcline, orthoclase, albite, and anorthite are of commercial importance, and these in the order given. Anorthite is of relatively small importance but is sometimes found in small quantities mixed with commercial albite, and a few large deposits are known. Contrary to popular belief, orthoclase is uncommon, most potash feldspars consisting chiefly of microcline.

Theoretically pure feldspars of any type are not found in commercial quantities. Thus, the best potash spars practically always contain a small percentage of soda. This is illustrated by the analyses of a few commercial feldspars in Table 2.

In typical feldspars of commerce "potash" spars always contain soda in ratios of from 6 or more parts of potash spar to 1 of soda down to as low as 3 parts potash to 1 of soda. "Soda" spars contain from 4 to 9 per cent soda (Na_2O) with a ratio of soda to potash spars of from $1\frac{1}{2}:1$ to $6:1$. All commercial spars contain some lime spar, from about 1 to 6 or 7 per cent, and free silica such as quartz from 1.5 per cent to as high as 25 per cent. Altered spars also contain more or less kaolin. Since the three types of spars, potash, soda, and lime, are usually microscopically intergrown it is impossible to judge the composition of a spar from its appearance, except to note such obvious impurities as iron staining, garnets, hornblende, mica, tourmaline, and large quartz inclusions.

Physical Properties. The physical properties of all varieties of feldspar are remarkably similar and can therefore be stated together in general terms. *Hardness*, 6 to 6.5. *Specific gravity*, 2.55 to 2.75. *Melting point*, 1185 to 1490°C. *Index of refraction*, orthoclase, 1.518 to 1.526; microcline, 1.522 to 1.530; albite, 1.525 to 1.536; anorthite, 1.576 to 1.588. *Color*, white, gray, brown, salmon, pink, yellow, and green. *Streak*, white. *Luster*, vitreous to pearly. *Cleavage*, good in two directions at or nearly 90 deg to each other; fracture uneven. *Transparency*, usually opaque, sometimes translucent, rarely transparent. *Tenacity*, brittle.

Competitive Materials. In most of the important uses for feldspar it is used as a ceramic fluxing agent and/or a source of alkalies and alumina. Until perhaps 25 years ago or less feldspar had almost no competitors for such uses, except for the feldspathic derivative, Cornwall stone. Today, in its various ceramic applications there are a large and growing number of direct or partial substitutes for feldspar. Among these are nepheline syenite, aplite, talc, pyrophyllite, slag, garspar, and lithospar, a blend of feldspar with spodumene.

The term "garspar" has been applied to the intimate mixture of finely ground glass and quartz produced by the grinding and polishing of plate glass with silica sand. Large tonnages of this material have accumulated, and reserves of as high as 15 million tons have been estimated to be available. In composition it averages around 15 per cent glass and 85 per cent silica. Some iron in the form of abraded metallic particles and rouge is present. The material is very fine and 95 per cent will pass a 325-mesh screen. Extensive research has been carried on to determine means of beneficiation and possible markets. It has been used as a filler in battery boxes and rubber where its fine grain size is valuable. In ceramic bodies it may be substituted for part of the feldspar and part of the flint. Research is in progress to investigate this usage further and also to determine its usefulness as an ingredient in the raw batch for glass manufacture.

Aplite is a highly altered, massive, white rock, occurring in large deposits near Piney River, Amherst and Nelson Counties, Va., composed of albite and microcline feldspars, sericite, zoisite, clinozoisite, and other minerals. A typical average analysis as reported by one of the producers shows SiO_2 , 57.75 per cent; Al_2O_3 , 24 per cent; Fe_2O_3 , 0.80 per cent; CaO , 5.6 per cent; Na_2O and K_2O , 9.15

per cent; and loss on ignition, 0.70 per cent. The soda content is a little more than twice the potash content. By high-intensity magnetic separation the iron can be reduced to 0.2 or 0.3 per cent, which is much too high for clear glass. Its original use was in colored glass such as beer bottles, but has expanded to other containers, flat glass, and glass fibers. Production began in 1938 and has increased greatly. In 1949 two mills were in operation, but production figures are not published.*

Pumice, granite waste, volcanic glasses such as obsidian, slags, and silica-alumina-alkali rocks such as alaskite are all being tested and considered as feldspar substitutes. In addition, projects are being considered or are under way for the extraction of feldspar from feldspathic sands, as at Weiser, Idaho, and in Illinois,³¹ from rocks high in feldspar such as granite,⁸ and from mill tailings such as those from titanium ore concentration in Virginia.²³ All these developments are due in part to the changing geographical distribution of consuming industries, in part to the desire to find uses for industrial wastes, and in part to the depletion of our better and more easily accessible deposits of feldspar. The recovery of feldspar from sands and rocks has been made possible by the development of successful froth flotation and agglomerate tabling methods.

As in many nonmetallic mineral industries, the economics of the feldspar industry cannot be considered without taking into account several competitive minerals.

Occurrence. Feldspar is found commercially in pegmatite dikes associated with quartz, biotite, and muscovite mica; minor quantities of tourmaline, beryl, garnet, spodumene, and other typical pegmatite minerals; as well as minor amounts of metallic minerals such as pyrite and magnetite and, rarely, columbite and tantalite. Although pegmatite deposits are widely distributed geographically, feldspars sufficiently free from impurities and occurring in large, easily mineable bodies are not so common. By the use of flotation, however, many deposits higher in impurities than could be worked by older milling methods are now of commercial interest. Because of the relative abundance of acceptable material and low unit value, feldspar does not enter largely into world commerce.

United States. The geographical distribution of important feldspar production in this country has changed greatly in the last two decades, due chiefly to the rise in importance of South Dakota, Colorado, and Wyoming. For many years North Carolina has maintained its position as the leading producer, but Maine, once second in tonnage but first in value, has dropped down far in the list, while new producers, such as Texas, Virginia, and Wyoming, have appeared. Although the major markets for feldspar are east of the Mississippi and north of the Ohio the western producers have been able to compete and prosper due to better deposits (resulting in lower costs) and very low per-ton-mile freight rates. Many eastern deposits have been exhausted or so depleted of their high-grade spar that production can be maintained only by close hand sorting or mechanical concentration, or else deposits farther from transportation must be opened—all entailing higher

* See P. S. Dear, and J. W. Whittemore, *Aplite, A New Ceramic Material* (abs.), *Am. Ceram. Soc. Bull.*, Vol. 18, No. 4, p. 138, April, 1939.

Also see W. E. Trauffer, *Piney River Plant Processes Virginia Aplite: Mineral Used in Glassmaking, Pit and Quarry*, Vol. 34, No. 3, pp. 44-45, September, 1941.

production costs. Sources of feldspar are sufficiently abundant so that economics, more than any other factor, determines the success or failure of any feldspar venture.

North Carolina feldspar deposits are in the western part of the state, principally in Mitchell, Yancey, Swain, Macon, and Jackson counties. *South Dakota*¹² production comes from the huge Harney Peak pegmatite area of the Black Hills near Keystone and Custer. *Virginia*,⁶ an important producer only in recent years, rose to third place in 1945. The deposits are in the western part of the state, mainly in Bedford County but extending into Henry, Pittsylvania, Campbell, Amherst, and Nelson counties. In *Colorado*¹² before the war at times a larger producer than South Dakota, production is centered around Canon City in the south central part of the state. *Connecticut* production comes mostly from deposits along the Connecticut River near Middletown. *Wyoming* has become an important producer in recent years from deposits in Albany County near Laramie and in Fremont and Natrona counties. In *New Hampshire* the pegmatites of the Grafton and Keene districts, largely in Grafton, Sullivan, and Cheshire counties, have been the most important producers of feldspar. In *Maine*, deposits in Cumberland, Oxford, and Androscoggin counties in the southern part of the state have long been producers, though now of much lessened importance. *New York* has produced feldspar for many years from deposits in Westchester, St. Lawrence, Fulton, Essex, and Saratoga counties. In *California* deposits are noted in 25 counties but, since west coast consumption has been relatively small, feldspar production has not been large. The deposit near Campo has been a fair-sized producer. In the spring of 1947 it was announced that a new 20-ton mill was being built at Rosamond, Kern County, to serve a local deposit. In *Arizona* a deposit south of Kingman has been a small but steady producer. *Other states* which are or have been small producers or which have deposits of commercial interest are Pennsylvania, Maryland, Georgia, Minnesota, Massachusetts, Texas, and New Mexico. From 1942 to 1945 feldspar was produced in 13 states.

The distribution of grinding mills by states is not quite the same as the distribution of deposits. Considerable crude feldspar moves by rail, often long distances, from deposits to grinding mills. For example, feldspar ground in Tennessee comes from North Carolina; Illinois ground spar comes from South Dakota or Wyoming; and the New Jersey ground spar may originate in any of the eastern states or in Canada. In 1945 there were 30 active grinding mills in 13 states. In addition, some consumers buy crude spar and grind it themselves, although this practice is less common than formerly and now the tonnage involved is small.

Canada. High-grade feldspar occurs in numerous localities in Canada, but production has never reached a very large volume due to the fact that Canada has not been sufficiently industrialized to provide important Canadian markets for feldspar and due to distance from railroads and to long freight hauls to markets in the United States. In the last 10 years production has ranged from 11,000 to 25,000 tons per year, averaging about 20,000 tons. Formerly, most of the Canadian production went to the United States as crude spar. In more recent years several Canadian grinding mills have been operated to supply growing

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Canadian markets. In 1945 about 35 per cent of the crude production was shipped to the United States. Centers of Canadian production have changed with the years, but the most important districts have been the following: in Ontario, Verona, Frontenac County; Bancroft, Hastings County; Sudbury district; Mattawa, Nipissing district; Parry Sound district; and Perth, Lanark County. In Quebec most of the production has come from deposits in the Lièvre River district, north of Buckingham, Papineau County.

United Kingdom. Very little pure feldspar occurs in Great Britain, and most of the feldspathic material used in the British potteries is "Cornish stone" or "china stone." Cornish stone is a local variety of decomposed granite, consisting mainly of feldspar and quartz, with varying amounts of kaolin, muscovite, fluor-spar, and topaz as accessory minerals. Four varieties are marketed: hard purple, mild purple, dry white, and buff stone, based on varying degrees of alteration or kaolinization. Typical samples of this material have the following approximate composition in percentages:

Type of stone	Kaolin	Feldspar	Quartz
Hard purple..	6.7	77.2	16.1
Buff.....	14.6	55.5	30.9

The feldspar in the stone is a mixture of orthoclase and albite, with the former predominating. Cornish stone is mined in the St. Stephen district near St. Austell in Cornwall, in conjunction with china clay. High-grade, pure feldspar needed by British industry is imported largely from Sweden.

Sweden. Sweden is an important producer of feldspar, and pegmatite dikes are abundant in many sections. The most important deposits are near Margretelund a few miles northeast of Stockholm, near Kolsva in the Vestmanland district, and near Drom in Östergötland. Many other good deposits are scattered over the country. Feldspar-grinding mills are located at Klinktjarn near Kolsva and at Baldersnas near Stockholm. At the former mill the spar is mainly graphic granite with about 20 per cent quartz. Some feldspar is used locally in porcelain and enameling plants, but most of the output is ground and shipped in bags to the Continent. Norway and Sweden supply most of the feldspar for British and Continental consumers. Before the Second World War Sweden produced 40,000 to 45,000 tons of feldspar per year.

Norway probably produces more feldspar than Sweden, but production figures are not available. Norwegian feldspar is exclusively potash spar and has been noted for its purity. The principal workings for many years were in the Arendal district, but later deposits were opened at Bergen, Kragero, Farsund, Flekkefjord, Stavanger, Haugesund, Drammen, Osterrisor, Kristiansand, Halvorsøi, Narvik, and Budo. Most of the feldspar used in the Royal Porcelain Works, Copenhagen, is obtained from the Naresto quarry, between Tvedestrand and Arendal. Just prior to the Second World War Norway produced 24,000 to 27,000 tons of feldspar per year.

Other Countries. Aside from the countries noted above the following countries have reported feldspar production in recent years ranging from around 1,000 tons to about 13,000 tons per year: Argentina, Australia, Finland, Germany (Bavaria), British India, Italy, and Spain. Czechoslovakia is reported unofficially to have produced about 30,000 metric tons per year. Other countries that have produced limited tonnages of feldspar are Brazil, China (Manchuria), France, Union of South Africa, Northern Ireland, Madagascar, Palestine, and Uruguay.

World Production. Table 3 (from "Minerals Yearbook," U.S. Bureau of Mines) shows the approximate world production of feldspar in recent years.

TABLE 3. WORLD PRODUCTION OF FELDSPAR, 1939 TO 1946, BY COUNTRIES, METRIC TONS^a
(Compiled by B. B. Mitchell)

Country ^a	1939	1940	1941	1942	1943	1944	1945	1946
Argentina (shipments).....	1,051	1,220	2,981	5,622	2,000	3,468	b	b
Australia:								
New South Wales ^c	51	64	452	1,469	3,890	4,756	3,785	b
South Australia ^c	615	1,072	1,081	1,026	522	818	955	1,317
Victoria.....		10	69	175	58	143	217	
Western Australia.....	3,853	3,561	4,173	3,304	2,351	1,990	1,254	1,822
Canada (shipments).....	11,306	19,464	23,623	20,203	21,644	21,327	27,439	32,993
Chile.....					8	b	124	b
Egypt.....	74	138	52	19	20	50	40	b
Finland (exports).....	5,596	721	1,223	2,328	1,288	2,080	233	b
France.....	b	b	b	14,870	19,340	9,609	8,433	26,557
Germany, Bavaria.....	11,436	12,762	12,973	12,332	12,842	41,200	b	b
India.....	501	999	1,257	2,100	b	b	b	b
Italy.....	12,473	10,538	12,758	.....	b	b	b	b
Japan.....	4,109 ^d	2,874 ^d	2,436 ^d	2,527 ^d	2,939 ^d	2,313 ^d	1,377 ^d	7,514 ^e
Madagascar.....	b	b	b	9	2	34	b	b
Norway.....	24,288	6,782	7,527	6,269	5,712	7,108 ^f	1,579 ^f	7,320 ^f
Palestine.....	b	b	b	b	85	65	37	b
Rumania.....	2,140	2,127	749	1,383	1,261	b	b	b
Spain.....	b	b	b	4,251	1,093	2,567	1,400 ^g	2,804
Sweden.....	40,792	22,222	21,988	19,243	25,879	15,537	15,172	b
Union of South Africa.....	b	b	b	b	b	669	b	b
United Kingdom:								
Great Britain.....	b	b	b	b	10	203	b	b
Northern Ireland.....	b	b	b	b	b	172	.....	b
United States (sold or used).....	257,534	295,430	344,299	321,240	313,126	332,663	379,042	516,539
Uruguay.....	b	b	b	b	b	264	265	b
Total ^h	390,000	400,000	450,000	425,000	425,000	460,000	480,000	650,000

^a In addition to countries listed, feldspar is produced in Brazil, China, Czechoslovakia, and U.S.S.R., but data are not available.

^b Data not available.

^c Includes some china stone.

^d Preliminary data for fiscal year ended Mar. 31 of year following that stated.

^e January to October, inclusive.

^f Exports.

^g January to September, inclusive.

^h Estimated by senior author of the chapter. No estimates are included for countries listed in footnote a.

United States Production and Consumption. Since little or no ground feldspar is imported into the United States and since exports are very small, Tables 4 and 5

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(from the "Minerals Yearbook," U.S. Bureau of Mines), which include ground spar made from imported Canadian crudes, are close approximations of both production and consumption, with one exception. Figures shown are for grinding mills that sell their output to the trade and do not include spar ground by captive mills. One large company making an abrasive soap both mines and buys crude spar and grinds it for exclusive use in its own products. This fairly large tonnage is not here included.

TABLE 4. GROUND FELDSPAR SOLD BY MERCHANT MILLS* IN THE UNITED STATES, 1944 TO 1948

Year	Active mills	Domestic			Canadian			Total	
		Short tons	Value		Short tons	Value		Short tons	Value
			Total	Average		Total	Average		
1944	28	335,491	\$3,714,039	\$11.07	7,710	\$148,997	\$19.33	343,201	\$3,863,036
1945	30	372,377	4,062,077	10.91	9,351	184,884	19.77	381,728	4,246,961
1946	28	454,869	5,029,330	11.06	15,330	316,777	20.66	470,199	5,346,107
1947	26	464,179	5,461,576	11.77	18,521	399,565	21.57	482,700	5,861,141
1948	28	487,070	5,991,059	12.30	19,381	471,172	24.31	506,451	6,462,231

* Excludes potters and others who grind for consumption in their own plants.

TABLE 5. GROUND FELDSPAR SOLD BY MERCHANT MILLS* IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944			1945			1946		
	Active mills	Short tons	Value	Active mills	Short tons	Value	Active mills	Short tons	Value
California.....	3	1,188	\$ 17,688	3	809	\$ 11,911	2	294	\$ 5,276
Colorado.....	3	45,365	318,696	3	41,433	307,619	2	55,251	448,011
Connecticut.....	1	22,079	409,875	{ 2 }	19,139	355,578	{ 2 }	22,464	405,828
New Jersey.....	3			{ 2 }			{ 2 }		
Maine.....	2	11,184	178,049	2	9,746	156,618	3	14,822	235,636
North Carolina..	3	110,251	1,326,861	{ 4 }	142,208	1,665,634	{ 4 }	207,527	2,194,552
Tennessee.....	2			{ 2 }			{ 2 }		
Undistributed†..	11	153,134	1,611,867	12	168,393	1,749,601	11	169,841	2,056,804
	28	343,201	\$3,863,036	30	381,728	\$4,246,961	28	470,199	\$5,346,107

* Excludes potters and others who grind for consumption in their own plants.

† Includes (number of active mills in parentheses) Arizona (1), Illinois (1), New Hampshire (2 in 1944 and 1946, 3 in 1945), New York (3), South Dakota (2), and Virginia (2).

The figures given in Tables 4 and 5 for feldspar consumption do not give a complete picture of the market for feldspathic fluxes, since they do not include the sales of aplite, nepheline syenite, ceramic talc and pyrophyllite, and other minerals

that are direct or partial substitutes for feldspar in the ceramic industries. While each material has its own special properties, they are all more or less competitive on a delivered price vs. analysis basis.

Since 98 to 99 per cent of the total merchant production of feldspar goes to the ceramic industries, chiefly pottery, glass and enamelware, it follows that the principal feldspar markets are the large centers of pottery, glass, and enamelware production. The container division is by far the largest feldspar user in the glass industry.

Table 6 ("Minerals Yearbook," U.S. Bureau of Mines) shows the approximate distribution of feldspar sales.

TABLE 6. GROUND FELDSPAR SHIPPED FROM MERCHANT MILLS IN THE UNITED STATES, 1942 TO 1946 BY DESTINATIONS, SHORT TONS

Destination	1942	1943	1944	1945	1946
California.....	12,224	8,669	9,788	8,735	8,641
Illinois.....	50,450	49,302	49,434	53,114	68,737
Indiana.....	38,998	40,873	40,057	47,321	47,756
Maryland.....	8,745	9,028	7,593	9,411	18,374
Massachusetts.....	3,630	3,855	3,508	3,258	3,009
New Jersey.....	43,029	40,259	38,158	35,735	41,340
New York.....	18,363	18,024	21,886	19,005	19,420
Ohio.....	43,950	42,536	41,208	48,151	47,031
Oklahoma.....	8,002	*	*	*	14,411
Pennsylvania.....	40,013	36,190	47,803	47,217	70,706
Tennessee.....	3,507	2,677	4,983	8,881	18,337
West Virginia.....	35,161	48,940	45,658	58,653	66,024
Wisconsin.....	7,837	8,718	7,993	7,058	10,317
Other destinations†.....	13,877	26,739	25,132	35,189	36,096
	327,786	335,810	343,201	381,728	470,199

* Included under "Other destinations"; separate figure for state not available.

† Includes Arkansas, Colorado, Connecticut, District of Columbia, Hawaii, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Oklahoma (1943 to 1945). Puerto Rico, Rhode Island, South Carolina, Texas, and states receiving shipments that cannot be segregated; also small shipments to Belgium, Canada, England, and Mexico.

Mining and Milling. Most feldspar is mined today, as it always has been, by open-pit or quarrying operations, although a few exceptional deposits are mined by underground methods. Individual operations tend to be small in size, ranging from small pits worked by two or three men to larger quarries employing ten or a dozen men or more. Mines are usually small and irregularly developed and operated, and productions as great as 50 tons per day from any one mine are unusual. It is very difficult to say what constitutes a deposit of commercial size or quality today. Because of improved roads and the general use of motor trucks, deposits once considered too remote to be operated profitably are now being worked. With improved methods of milling, such as the use of magnetic separation and flotation, impurities in a deposit do not present the insurmountable barrier that they once did.

With the geographical dispersion of consuming industry across the country, deposits that were once too far from market to be considered are today becoming of interest. Today "place value" is perhaps of greater importance than inherent quality in a deposit, although quality still is important due to its influence on the cost of milling. A relatively low-grade deposit, of large size and easily worked close to a mill or to a railroad and near important markets, may be more valuable than a high-grade deposit remote from transportation and markets. A good, high-grade deposit is one that is 15 to 20 ft or more in width, at least one-third of which is clean, fresh feldspar that may be readily broken free from associated minerals in large, blocky masses. It should be free from iron stains and from finely disseminated garnet, tourmaline, mica, and other impurities; quartz should constitute not over 25 per cent of the shipping product. Mica and beryl, if they may readily be separated from the feldspar in fairly large pieces that can be sorted by hand, may be valuable by-products. What constitutes a good, low-grade deposit depends largely on milling costs and costs of transportation to mill and to market. Large size is important; iron staining is an unfavorable though not necessarily incurable fault.

Although a few small pits may be still worked by hand drilling, compressed air drills are now almost universally used. Hand sorting and hand cobbing are still practiced in the smaller mines. In a few operations power shovels are used, but hand loading of cars or trucks is general since it permits impurities to be discarded. In some areas, as in North Carolina, considerable spar in the aggregate is mined by individuals from their own or leased deposits and hauled to dumps at railroad sidings, where buyers from grind-mill companies evaluate and purchase their spar.

Feldspar milling was for many years and with very few exceptions so simple an operation that practically a standardized flow sheet was used. This flow-sheet, shown in Fig. 6, is still the basis for many of the smaller mills. It is well adapted to the grinding of spar of uniform composition from a single deposit or from several closely similar deposits, where the spar contains no deleterious impurities and where only finely ground spar is to be made.

The milling problems are basically simple, namely, to make finished products free from impurities that may cause specking or discoloration of ceramic wares and uniform in chemical composition and in fineness of grind. In practice this may not be easy or simple except when grinding very pure, uniform spar from a single deposit. As such deposits become scarcer it became necessary for a single mill to use spars from many different sources, of varying composition and of varying degrees of purity. Also the demands for granular spar for glassmaking increased enormously, and provision had to be made for making this type of product in quantity.

In grinding spars from a few different sources, when each spar is fairly pure and uniform, the problem has been met by storing each type separately, grinding them separately, cleaning out the system between each two types, and binning and selling each type as a separate grade. Blending of types by guess has been practiced with results varying from fair to poor. The problem of blending and of making uniform, standard, chemically controlled grades has been met by different

producers by the development of flow sheets of varying degrees of complexity. Probably the most elaborate and complicated of the chemically controlled mills is that of the Tennessee Mineral Products Corp. at Spruce Pine, N.C.⁵ The essential features of this mill are (1) separate binning of all different types of crudes (8,300 tons crude storage in 43 bins); (2) separate crushing, screening, and drying of each type; (3) automatic sampling and chemical analysis of stream from

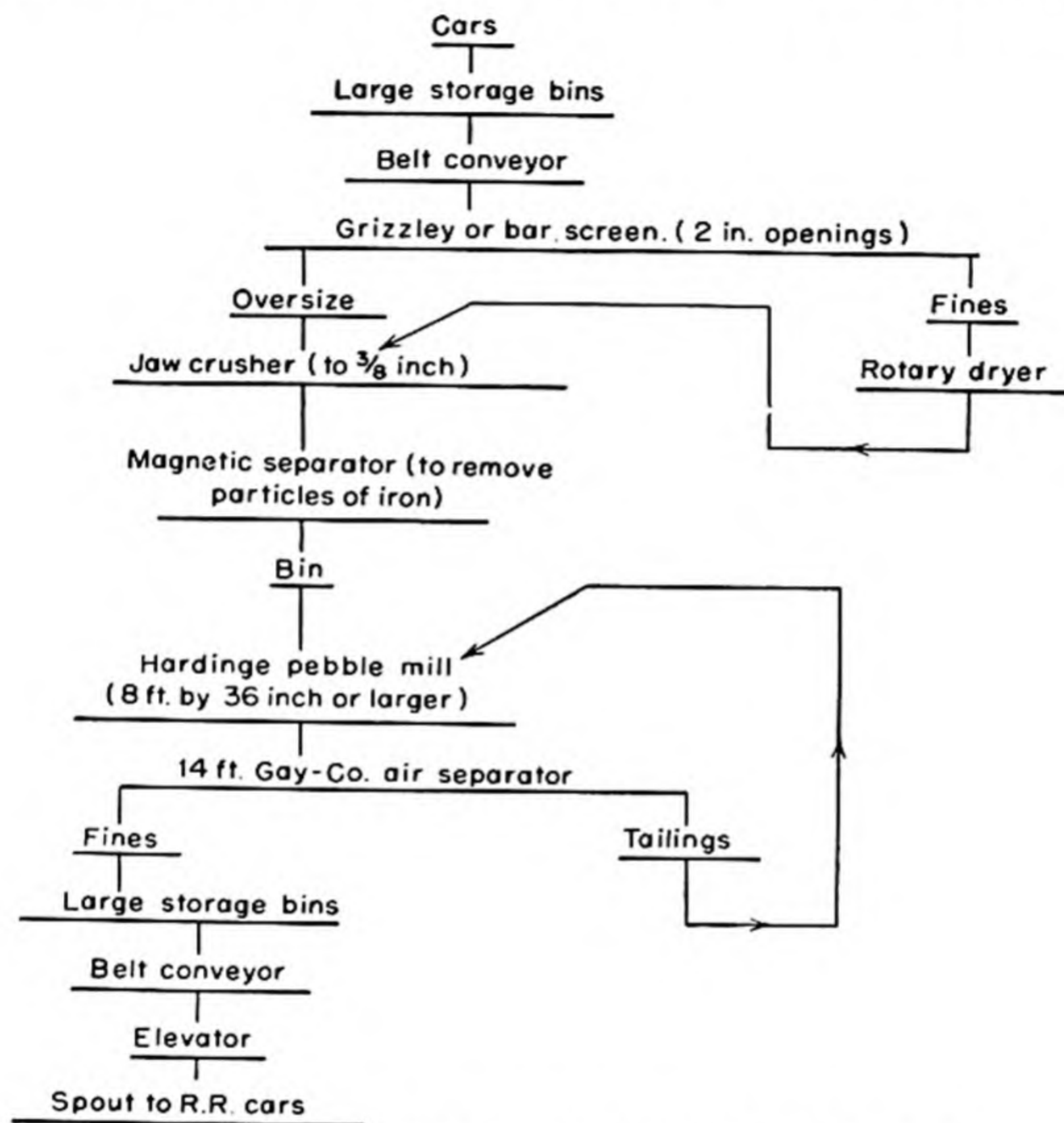


FIG. 6. Generalized flow sheet of feldspar grinding mill.

drier to each of twenty 80-ton crushed storage bins, so that chemical composition of spar in each bin is known; (4) drawing off calculated amounts of spar from selected bins to make grade of desired analysis; (5) binning in one of three 50-ton blending bins; (6) grinding in one of several Hardinge conical pebble mills in closed circuit with screens (coarse products) or air separators (fine products); (7) automatic sampling and analysis; (8) shipment or storage.

Granular, glass-grade spar may be made either as a primary product with a separate flow sheet following a secondary crusher or as a coproduct when making

the fine-ground grades. The object is to make a 20-mesh product free of minus 150-mesh fines. As a primary product the spar may be stage-crushed (to minimize fines) in several sets of rolls with screening on Hum-mer or similar vibrating screens to remove 20-mesh product between each two stages until all material is -20 mesh. This product may then be run through an air separator to remove minus 150-mesh dust. When made as a coproduct the Hardinge conical pebble mill may be operated so as to produce a large percentage of coarse grains, the discharge screened on double-decked screens with the plus 20-mesh oversize returned to the mill, the minus 20- plus 140-mesh recovered as glass spar, and the minus 140-mesh product air-separated and reground for pottery-spar grades.

Glass-grade spar must be very low in iron (under 0.06 per cent Fe_2O_3 for best grades), so low that few crude spars today can meet the specification without beneficiation. The best dry-grinding mills today pass the 20-mesh glass spar through high-intensity magnetic separators. The most efficient of these separators¹⁶ will remove not only garnet, magnetite, and biotite mica, but also a considerable portion of feebly magnetic muscovite mica. It is best to divide the feed into two or more size fractions and treat each separately. Dust finer than about 150 mesh cannot be treated effectively by dry magnetic separation.

Froth flotation of feldspar, first accomplished in 1936 and reported in 1939,¹⁸ is now used commercially by several companies to separate feldspar from quartz. Flotation alone is adapted only to fine powders but, by agglomerate tabling, granular glass-grade spar may also be separated. Details of the actual commercial operation of flotation plants have not been revealed but their success seems assured, at least from a technical standpoint. By the use of these new methods not only may lower grades of crudes be used, but also quarrying operations may be mechanized and conducted on much larger, more efficient bases at lower costs.

Marketing and Shipping. Crude feldspar is sold on the long-ton basis, usually fob cars shipping point. The price paid depends upon the buyer's estimate of grade, which may be made either before loading or upon unloading at the grinding mill. Crude spar is preferably shipped in bulk in boxcars, because in open-top steel cars iron rust may contaminate the product. Ground feldspar is sold on the short-ton basis, fob cars grinding mill, and the price is usually based on the grinder's estimate of quality, subject to acceptance or rejection by the buyer. It is shipped either in bulk in boxcars or packed in paper or burlap bags. When it is shipped in bulk the boxcars are carefully cleaned and sometimes lined with building paper to ensure cleanliness. Often the ground spar is sprinkled with water as it is loaded to lay the dust. This practice is also said to make the unloading less disagreeable.

The consumers of ground feldspar do not customarily maintain large stocks, and they are more or less dependent on current shipments. Neither do feldspar grinders usually have facilities for storage of their finished product in large quantities. Crude feldspar is often stock-piled in large quantities at the quarries, at the railroad shipping points, and at the mills, but large bin storage is not common. Stock-pile storage is expensive, because in most cases the spar must be reclaimed by shovel and wheelbarrow.

Specifications and Tests. Commercial standards for feldspar were promulgated by the Division of Trade Standards of the National Bureau of Standards on Sept. 1, 1930, and generally accepted by the feldspar producers and ceramic consumers. This, known as Commercial Standard CS23-30,* was considered by miners and some small grinders as too rigid and complicated, and on Dec. 4, 1935, the Feldspar Association published a modification of these standards, simplifying them and making them a little less onerous.

The CS23-30 specifications cover fineness of grinding, chemical classification based on composition as it influences use, and standard methods of chemical analysis. They are not in common use today.

Prices. Feldspar is sold by the net ton. In 1950 prices were quoted as follows: enamel, 100 mesh in bags at works, \$17.00 to \$20.50 per ton; bulk, carloads, \$14.00 to \$17.50; glass, 20 mesh in bags at works, \$12.75 to \$16.25 per ton; bulk, carloads, \$9.75 to \$12.25; pottery, bulk, carloads at works, \$17 to \$19 per ton; bags, \$20 to \$22 per ton.

Utilization. The distribution of feldspar consumption by uses has changed greatly in the past 20 years. Uses other than ceramics, once totaling 16 per cent of the production, have dwindled to 1 or 2 per cent. In the ceramic industries, where once the use in glass was of minor importance, glassmaking today takes nearly two-thirds of the production, although the tonnages used in pottery and enamel have not decreased. In other words, the great expansion in feldspar production has been caused very largely by greatly increased demand from the glass industry. Table 7 (U.S. Bureau of Mines, "Minerals Yearbook") shows the approximate distribution of sales by uses.

TABLE 7. GROUND FELDSPAR SOLD BY MERCHANT MILLS IN THE UNITED STATES, 1944 TO 1946

Use	1944		1945		1946	
	Short tons	Per cent of total	Short tons	Per cent of total	Short tons	Per cent of total
Ceramic:						
Glass.....	220,734	64.3	249,927	65.5	289,559	61.6
Pottery.....	106,341	31.0	111,695	29.3	154,340	32.8
Enamel.....	8,464	2.5	13,755	3.6	22,500	4.8
Other ceramic uses..	849	0.2	1,747	0.4	144	
Soaps and abrasives...	6,424	1.9	4,245	1.1	3,081	0.7
Other uses.....	389	0.1	359	0.1	575	0.1
	343,201	100.0	381,728	100.0	470,199	100.0

Feldspar is used in glassmaking primarily for its content of alumina, although its alkali content aids in fluxing and serves to replace a portion of the other forms of alkali needed. The substitution of alumina for part of the silica in a commercial lime glass (1) increases its toughness or resistance to breakage from impact

* Available at Supt. of Documents, Government Printing Office, Washington, D.C.

(very important in container glass); (2) increases resistance to scratching, which adds to strength; (3) increases resistance to breaking due to bending (important in window glass); (4) increases tensile strength and thus its thermal endurance; (5) increases chemical durability; and (6) decreases tendency toward devitrification. The general use of feldspar in container glass and the greatly increased use of glass containers have made this the most important single market for feldspar. This market, however, has to be shared with nepheline syenite and aplite, both of which have a higher content of alumina than the best feldspar (24 to 25 per cent against a range of 16 to 19 per cent for feldspar). Aplite, however, is too high in iron for clear glass containers.

Some work has been done on the use of anorthite or lime feldspar for glass-making. Its high theoretical content of alumina (36.62 per cent) is about twice that of the average potash-soda feldspar sold to the glass trade, and extensive deposits are known, as in the anorthosites of Minnesota.⁹ The chief difficulty is, as usual, economic. In the ordinary feldspars, aplite and nepheline syenite, the potash and soda content replace equal amounts of soda from soda ash. Anorthite, theoretically, has no soda or potash, and its content of lime, about 20 per cent, would merely replace the lime in a glass batch which usually comes from very cheap ground limestone. Thus, the dollar value of anorthite to a glass-maker may not be as high as that of other sources of alumina. For glass plants in some areas, however, anorthite may offer the cheapest source of alumina. In typical glass batches from 50 to 200 lb of feldspar per 1,000 lb of glass sand may be used.

In pottery and tile bodies feldspar content may run from 10 per cent to as high as 55 per cent (floor tile), and in enamels and glazes the feldspar content may range from 30 to 50 per cent of the mix. For electrical and dental porcelain exceptionally high-grade spar, usually high-potash spar, is needed. In the white-ware industries, particularly in wall tile, talc and talc-pyrophyllite mixes have replaced feldspar to an important extent.

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FLUORSPAR—FLUORITE

Composition. Fluorspar is a calcium fluoride, CaF_2 , calcium, 51.1 per cent; fluorine, 48.9 per cent.

General Description. Fluorspar is a moderately hard, glassy, transparent or translucent mineral, crystallizing in the isometric system, usually in the form of cubes. Often crystals are twinned so that corners of cubes protrude through the cubical faces. Crystals have a good octahedral cleavage, so that perfect octahedrons may be easily formed. It commonly occurs as crystalline masses and frequently in well-formed crystals, less often in granular form. In color, it varies from green to white, purple, blue, yellow, pink, brown, and gray.

Except for cryolite, which is treated elsewhere in this work, fluorspar is the only primary mineral source of fluorine for industrial use. The only other potential source of large amounts of fluorine is phosphate rock, which usually contains 2.5 to 3.5 per cent fluorine. This source will be discussed later in this section.

Physical Properties. *Hardness*, 4. *Specific gravity*, 3.01 to 3.25. *Melting point*, 1270 to 1387°C (about 900°C also given, but probably this represents impure material). *Index of refraction*, 1.434. *Color*, green, purple, blue, yellow, brown, pink, gray, black, white, colorless. *Streak*, white. *Luster*, vitreous. *Cleavage*, octahedral (good). *Transparency*, transparent, translucent, to nearly opaque. *Tenacity*, brittle.

Occurrence. Compared with many of our industrial minerals, such as feldspar, for example, fluorspar is a scarce mineral. Known world's reserves in accessible deposits are not adequate to supply growing needs for a long term. Chemists working on new uses for fluorine are apparently not aware of the real world picture. For example, Simons has stated, "Fluorine is not a scarce element on the earth's surface; it is about as abundant as either nitrogen or carbon and more plentiful than chlorine on the land masses. From the standpoint of abundance and availability alone it could be expected that fluorine compounds would have extensive uses"* While this may be true technically, due to wide dissemination of fluorine in very small amounts in igneous rocks, it is not true practically, and it is very dangerous and fallacious reasoning. Although fluorspar deposits are known in many parts of the world, most of them are relatively small and many of them are inaccessible or of low grade.

Fluorspar deposits usually occur in the form of veins, deposited from hot solutions, in both sedimentary and igneous rocks. Common gangue minerals are galena, sphalerite, calcite, barite, and quartz. There are, in general, two distinct types of deposits where fluorspar is the principal mineral sought:

* "Fluorine Symposium," *Ind. Eng. Chem.*, Vol. 39, No. 3, p. 238, Mar. 14, 1947.

1. *In limestones.* Here deep-seated ascending vapors or hot solutions carrying fluorine gas or hydrofluoric acid attack limestone wall rocks, either forming CaF_2 by direct replacement or dissolving the CaCO_3 , forming CaF_2 in solution and later depositing fluorspar on limestone walls. Here the impurities are chiefly CaCO_3 , with low silica (from impurities in the parent limestone). At times barite accompanies the fluorspar and occasionally lead and zinc sulfides.

2. *In siliceous rocks such as rhyolites, granites, etc.* Here the ascending F and HF vapors react at depth with an insufficient supply of lime, perhaps from calcium silicates. The surplus F and HF then react with the silica in the wall rocks and finally deposit the mixture of CaF_2 and SiO_2 along the siliceous walls of the enclosing rocks.

In such deposits the fluorspar is low in CaCO_3 (often it is entirely absent) and high in SiO_2 and the sulfide minerals are usually absent or present in only very small amounts.

Another type of occurrence that has never been important commercially is as a minor accessory mineral in mixed ores of the metallic sulfides. Perhaps old mill-tailings dumps in the West could be found high enough in fluorspar to warrant reclamation at some time in the future.

The United States is the world's largest producer and consumer of fluorspar. Germany, under normal conditions, would probably stand second, with Russia probably third and Great Britain fourth. When world markets are good, Spain, Newfoundland, Mexico, and Korea are important producers but not consumers of fluorspar. At times France, Italy, Union of South Africa, and Canada are fairly large producers, both for their own use and for export.

United States production has always had as its mainstay the *Illinois-Kentucky* district that centers about Rosiclare, Hardin County, Ill. In 1946, 99.7 per cent of the Illinois production came from Hardin County and the balance from Pope County. These deposits extend across the Ohio River into Kentucky, where large production has come from Crittenden, Livingston, and Caldwell counties. In *Kentucky* there is also a less important central district in Woodford and Mercer counties. In the Illinois-Kentucky district the deposits most commonly are vertical or nearly vertical veins in fault fissures cutting flat-lying or gently dipping beds of limestone, chert, shale, and other sedimentaries. Less common are nearly flat, tabular deposits. On the Illinois side, workings in places have reached over 700 ft in depth, with widths of up to 25 or 30 ft. The most common accessory minerals are calcite, quartz, galena, sphalerite, and chalcopyrite. At a few mills both lead and zinc concentrates form valuable by-products.

Colorado, usually the third largest producer, has active deposits at Wagon Wheel Gap, Mineral County; near Jamestown, Boulder County; near Salida, Chaffee County; and near Northgate, Jackson County; and small production has come from near Jefferson, Park County.

In *New Mexico* production has come in recent years from Catron, Dona Ana, Grant, Hidalgo Luna, Sierra, and Valencia counties, and deposits are known in other counties. In *Nevada* the two important producing deposits have been near Broken Hills, Mineral County, and near Beatty, Nye County. *Arizona*, a small producer, has had working deposits in Cochise, Greenlee, Maricopa, and Yuma counties.

During the Second World War *Utah* produced some fluorspar from deposits near Milford and Lund, Beaver County, and near Delta, Juab County. In recent years some production has come from *Texas* (near Van Horn, Hudspeth County); from *Washington* (near Keller, Ferry County); and from *Tennessee* (near Rome, Smith County). Deposits are known in *Idaho* (near Forney and Meyers Cove, Lemhi County). Small production once came from Westmoreland, Cheshire County, *New Hampshire*.

In *Great Britain* the most important producing localities are Derbyshire and Durham, but good deposits also occur in Cornwall and North Wales. Originally, all these mines were worked for lead, and much of the fluorspar shipped in the past has been from old tailings dumps and from waste fillings in old mines. However, during the last war several old mines were reopened, and unexpected additions to reserves were developed.

*Germany.*⁹ During the Second World War German fluorspar production probably was close to 200,000 tons per year, and before the war she was an important exporter. Workable deposits are found in Bavaria, Thuringia, Anhalt, Prussia, Saxony, and Baden. The most important districts in order of production are in the Stulln-Nabburg-Woelsendorf area of Bavaria; near Rottleberode in the Harz Mountains; and in the Thuringian Forest. Reserves are not large, but with greatly lessened internal needs she could continue to export at her prewar rate of 30,000 to 40,000 tons per year for probably 20 years or more.

*Newfoundland.*²⁵ Fluorspar production in Newfoundland began in 1933 and reached a peak of over 66,000 tons in 1943. The deposits are located in the districts of Burin East and Burin West about 1 mile from the tidewater at Little St. Lawrence Bay. There are many veins, and reserves are reported to be large. Veins locally range from a few inches up to 14 ft of solid fluorspar and up to 35 ft of mixed fluorspar and granite breccia. The ore is beneficiated by hand picking, wet-gravity concentration, and froth flotation. All grades of product are as made.

Mexico. There are several known deposits of fluorspar in Mexico, but the largest is the Azul mine at Taxco in the state of Guerrero—controlled before the war by Japan. Other deposits have been worked in the states of San Luis Potosi (near Guadaluca); Sonora (Magdalena District); Zacatecas (Chalchihuites). During the war total Mexican production reached a maximum of over 56,000 tons (1944), most of which was shipped to the United States, but part to Canada; and some is used locally.

*Russia.*¹⁰ Little has been published in English about the Russian fluorspar industry, but it is reported that there are numerous deposits with large reserves and that as far back as 1937 her production was about 70,000 tons per year. Deposits are reported in Eastern Transbaikalia, in Kazakhstan, in Eastern Siberia, and Middle Asia.

*Spain.*² The most important fluorspar mines in Spain are in Asturias near Gijon and Ribadesella, which have a modern flotation plant. Other deposits are in Cordoba, Gerona, Barcelona, and Catalonia provinces. The Gerona deposits are extensive and were developed by the Germans.

France. Fluorspar deposits have been worked in at least 10 departments in France, but the most productive have been Var, Saône-et-Loire, Haute-Loire, and Puy-de-Dôme.

Other countries which add appreciably to world production are Union of South Africa and South-West Africa,¹⁶ China (northern Chekiang Province), Korea (South Chusei Province), Italy, Norway, Sweden, and Argentina.

TABLE 1. WORLD PRODUCTION OF FLUORSPAR, 1937, 1939, AND 1942 TO 1946, BY COUNTRIES, METRIC TONS^a
(Compiled by B. B. Mitchell)

Country ^a	1937	1939	1942	1943	1944	1945	1946
Argentina (shipments).....	350	739	2,328	4,000	b	b	b
Australia:							
New South Wales.....	55	.....	.....	.....	.....	.....	b
Queensland.....	1,410	20	311	544	520	801	875
Victoria.....	.....	.....	344	468	266	145	326
Canada.....	136	218	5,624	10,169	6,281	6,685	6,853
France.....	51,430	b	27,447	24,160	13,400	13,749	21,528
Germany:							
Anhalt.....	13,662	11,157	12,470	190,000 ^c	170,000	b	b
Baden.....	13,637	22,480	31,625				
Bavaria.....	62,455	69,870	59,640				
Prussia.....	30,514	24,414	27,841				
Saxony.....	8,074	10,002	11,806				
Thuringia.....	16,117	24,040	32,290				
India.....	.....	20	4,110	1,667	1,249	b	b
Italy.....	13,385	13,243	35,034	b	b	b	b
Japan.....	b	1,960	7,800	7,282	7,967	3,207	b
Korea (Chosen).....	8,084	22,000 ^c	47,847	50,000 ^c	60,000 ^c	b	b
Mexico (exports).....	b	.....	5,365	22,469	56,450	50,251	20,114
Newfoundland.....	8,479	11,227	32,660 ^c	66,170	58,290	49,841	25,266 ^d
Norway.....	1,692	2,411	1,920	905	3,119	b	b
Southern Rhodesia.....	.....	.....	b	b	b	b	b
South-West Africa.....	.....	105	b	b	b	.....	b
Spain.....	4,250	8,408	16,297	35,911	55,595	9,642	6,477 ^e
Sweden.....	b	.....	468	2,107	1,836	3,448	b
Switzerland.....	.....	.....	486	582	520	.....	b
Tunisia.....	1,676	2,010	b	16	.....	.....	b
Union of South Africa.....	3,615	10,322	4,185	4,646	3,481	3,657	4,004
U.S.S.R.....	70,000 ^c	b	b	b	b	b	b
United Kingdom.....	42,837	38,786	43,920	55,106	48,927	44,281	46,644
United States (shipments)...	164,408	165,806	326,871	368,330	375,374	293,891	252,142
Total (estimate).....	519,000	577,000	883,000	1,022,000	1,086,000	b	b

^a In addition to countries listed China produces fluorspar, but data of output are not available.

^b Data not available.

^c Estimate.

^d Exports.

^e January to September, inclusive.

Canada produces some fluorspar, chiefly from near Modoc, Hastings County, Ontario, but not enough for her own needs, and she must rely largely on imports, chiefly from Newfoundland, the United States, and Mexico.

FLUORSPAR—FLUORITE

TABLE 2. FLUORSPAR SHIPPED^a FROM MINES IN THE UNITED STATES, 1880 TO 1948, BY STATES, SHORT TONS^b

Year	Ari- zona	Colo- rado	Illinois	Ken- tucky	Nevada	New Mexico	Other states ^c	Total
1880-1909 ^d	718	5,807	330,120	203,929	.....	710	1,020	542,304
1910-1919 ^d	843	83,220	1,004,633	281,124	400	20,997	6,110	1,397,327
1920-1929 ^d	181	71,920	630,804	512,518	2,344	31,216	2,319	1,251,302
1930-1939 ^d	3,351	50,935	466,595	515,727	14,693	23,931	3,090	1,078,322
1940	1,370	11,032	104,698	103,939	5,803	6,616	142	233,600
1941	1,428	15,566	133,333	142,862	8,967	17,591	922	320,669
1942	714	31,743	161,949	134,133	8,020	22,542	1,215	360,316
1943	1,328	49,145	198,789	109,849	8,653	37,050	1,202	406,016
1944	976	65,209	176,259	112,791	7,293	42,973	8,280	413,781
1945	1,126	52,437	147,251	95,142	7,038	14,449	6,518	323,961
1946	389	32,539	154,525	63,143	6,234	17,584	3,526	277,940
1947	1,601	32,153	167,157	90,256	8,042	27,526	2,749	329,484
1948	1,271	27,698	172,561	84,889	9,615	24,968	10,747	331,749

^a Figures for 1880 to 1905 represent production.

^b Figures on production not recorded for Colorado before 1905, for Illinois before 1880, and for Kentucky before 1886 and for 1888 to 1895; total unrecorded production, chiefly from Illinois, estimated at 25,000 tons.

^c California, New Hampshire, Tennessee, Texas, Utah, Washington, and Wyoming.

^d Figures, by years, for 1880 to 1909 are given in Mineral Resources of the United States, 1925, pt. II, p. 13; for 1910 to 1939 in "Minerals Yearbook," Review of 1940, p. 1297.

TABLE 3. FLUORSPAR IMPORTED INTO THE UNITED STATES, 1910 TO 1946, BY COUNTRIES, SHORT TONS^a

Year	Africa	Canada	France	Ger- many	Mexico	New- found- land	Spain	United King- dom	Other coun- tries ^b	Total
1910-1919 ^c	.....	2,433	.....	1,227	.....	.....	.....	183,265	11	186,936
1920-1929 ^c	54,550	16,197	57,565	119,903	.....	.....	11,774	178,482	16,161	454,632
1930-1939 ^c	17,527	468	65,815	89,056	550	17,922	34,525	6,940	7,989	240,792
1940	.....	.....	5,735	.....	1,555	3,640	112	.....	829	11,871
1941	.....	.....	.....	.....	4,452	.....	3,070	2	.....	7,524
1942	.....	^d	.....	.....	2,151	.....	.....	.....	.....	2,151
1943	570	.....	.....	.....	20,515	7,144	15,540	.....	.....	43,769
1944	3,557	69	.....	.....	58,324	16,072	9,177	1	.....	87,200
1945	.....	2,361 ^e	.....	.....	62,575	10,875 ^c	27,332	.....	.....	103,133
1946	.....	310	.....	.....	24,063	2,688	2,791	.....	.....	29,852

^a Imports Aug. 1 to Dec. 31, 1909, totaled 6,971 tons. Earlier imports not separately recorded but estimated at 150,000 tons and virtually all from United Kingdom.

^b Argentina, Australia, Austria-Hungary, Belgium, China, Czechoslovakia, Italy, Netherlands, Norway, Tunisia, and U.S.S.R. in Asia.

^c Figures, by years, for 1910 to 1939 are given in "Minerals Yearbook," Review of 1940, p. 1298.

^d Less than 1 ton.

^e Bureau of Mines has determined that 1,691 tons credited to Canada by the U.S. Department of Commerce originated in Newfoundland.

United States Production and Consumption. Tables 2 to 4 show the United States production and consumption of fluorspar over an extended period of years. Of the total of nearly 8 million tons produced in or imported into this country from about 1870 through 1946, about 83 per cent was from domestic mines and 17 per cent from imports. Of our total domestic production of all time about 42 per cent was mined in the decade from 1937 to 1946.

TABLE 4. FLUORSPAR (DOMESTIC AND FOREIGN) CONSUMED IN THE UNITED STATES, 1929 TO 1948 SHORT TONS

Year	Steel	Hydro-fluoric acid	Glass	Enamel	Iron foundry and ferro-alloys	All other	Total
1929	162,100	15,600	6,600	5,200	3,800	1,500	194,800
1930	112,600	12,600	4,300	4,000	2,700	2,000	138,200
1931	69,300	12,000	7,100	3,000	1,300	1,300	94,000
1932	38,400	7,000	6,700	2,400	800	700	56,000
1933	64,700	7,800	7,000	3,200	1,200	700	84,600
1934	85,300	11,000	7,700	3,500	2,100	1,000	110,600
1935	105,000	12,900	11,000	4,900	2,600	1,000	137,400
1936	140,800	20,100	11,600	5,400	2,700	1,800	182,400
1937	146,400	24,100	11,600	5,900	3,700	2,600	194,300
1938	77,600	18,900	10,500	4,000	2,800	1,300	115,100
1939	123,800	26,300	15,300	6,100	3,500	1,800	176,800
1940	155,500	37,000	13,400	5,500	4,600	2,500	218,500
1941	210,400	56,000	20,300	7,300	5,100	4,500	303,600
1942	242,600	81,600	18,500	3,100	7,800	7,200	360,800
1943	234,148	113,614	20,592	1,726	7,260	11,545	388,885
1944	230,201	129,553	27,315	2,547	7,815	12,739	410,170
1945	197,916	109,315	31,874	3,695	6,786	6,504	356,090
1946	160,735	83,901	39,852	6,739	6,969	4,994	303,190
1947	209,395	100,363	42,130	8,938	6,567	8,745	376,138
1948	232,687	107,280	37,247	8,871	8,817	11,367	406,269

Mining and Milling. Practically all the fluorspar produced comes from underground mining operations, and mining methods closely follow those used in metal mines. Since two or three large mines on the Rosiclare vein in southern Illinois furnish a very large percentage of the domestic production, the operation of but one typical mine here will be described.

The Rosiclare vein stands nearly vertical between limestone walls and varies in thickness from 2 to 30 ft, averaging about 7 ft. Vertical shafts are sunk either in the vein or in one of the walls, levels are turned off in each direction along the vein at 100-ft intervals, and ore pockets are cut below the shaft stations. Drifts are cut 6 ft wide or vein width if veins are over 6 ft. Drifts are timbered

over and closely lagged at the top. Ore chutes are put in at the sides of the drift on 10 ft centers. The ore is broken down by overhand stoping on top of the drift timbers, and sufficient ore is drawn off from the chutes to leave working room on top of the broken ore. The stopes are then worked as shrinkage stopes up to within 10 ft of the level above, thus leaving longitudinal pillars to protect the drifts. From the chutes the ore is drawn off into steel mine cars, hauled to the shaft by locomotives (gasoline or storage battery) or by mules, and dumped into the shaft pocket. Hoisting is done in 3-ton skips and as much as 400 tons of ore can be hoisted from one shaft in an 8-hr shift. Drilling is done by compressed-air stopers and jackhammers. Ventilation is natural and very good. Pumping is a serious problem, 1,100 gpm of water being pumped from a single shaft. Underground prospecting by horizontal diamond-drill holes has been practiced, but has not been very successful.

At the smaller mines less systematic methods are followed, but in general fluor-spar mining is done efficiently.

Milling methods have undergone great changes since the introduction of froth-flotation methods commercially in 1929. Prior to that time concentration was either by hand sorting, by log washing, or by wet milling with jigs and tables to effect a gravity separation of fluorspar from gangue minerals. Where the gangue was predominantly calcite plus lead and zinc sulfides, satisfactory products could be made with relatively low tailings losses. But with siliceous ores, such as most of those in the western states, low-silica concentrates could not be made economically. The general use of flotation methods made many deposits commercially valuable that were previously worthless and very greatly increased our reserves.

In 1944 a further great advance in the art of fluorspar milling was made by the introduction of the heavy-media or sink-and-float process, whereby a large part of the gangue can be removed in coarse sizes more efficiently and at lower costs than with jigs and tables. Today both flotation and heavy-media separation methods are practically standard in all large mills and in many smaller ones, although jigs and tables are still found useful with some ores. The best milling methods for any ore depend upon the physical and chemical characteristics of that ore and can only be determined by laboratory study.^{1,4,5,6,15,18,19,23k}

Flotation is particularly well suited to the making of acid and glass-grade fluor-spar since the trade demand is for a finely ground product. For metallurgical use, however, the demand is for gravel and lump sizes, free from fines; and, to be acceptable to these trades, flotation concentrates must be briquetted, pelletized, or otherwise agglomerated into coarse, firm, strong aggregates that will stand transportation and handling without breaking down into fines. Considerable research has been done on binders and briquetting processes, but when natural gravel spar is obtainable it is generally preferred to any pelletized product yet developed. One company⁸ uses unrefined tall oil plus lime as a binder and presses pellets about $\frac{7}{8}$ by $\frac{5}{8}$ by $\frac{3}{16}$ in. in a roll briquetting press. These briquets are dried and cooled in a tray drier and then screened to remove fines before shipment.

Specifications and Grades. There are three general fluorspar grade classifications, based chiefly on type of use. These are the metallurgical, acid, and ceramic grades.

Metallurgical grade, sometimes called gravel grade, ranges in size from about $\frac{1}{2}$ in. down to dust. What is wanted is a coarsely granular material free from, or very low in, fine dust. Silica is objectionable, not because it is harmful but because when fluorspar is used as a flux, each per cent of silica in the spar requires about $2\frac{1}{2}$ per cent of CaF_2 to flux it, thus rapidly reducing the effective percentage of CaF_2 . Formerly, the standard grade of metallurgical spar called for a minimum of 85 per cent CaF_2 and a maximum of 5 per cent silica (known as "85 and 5" grade in the trade). This had an effective CaF_2 content of 85 per cent minus $2\frac{1}{2}$ times 5 per cent ($12\frac{1}{2}$ per cent), or 72.5 per cent. During the Second World War scarcity of fluorspar of all grades led to the use of lower grades. OPA price schedules called for recognition of four grades: (1) 70 per cent or more effective CaF_2 content, (2) 65 per cent but less than 70 per cent, (3) 60 per cent but less than 65 per cent, and (4) less than 60 per cent. A maximum of 0.3 per cent sulfur is usually specified. Lump metallurgical spar of the same general specifications is used by the foundry trade.

Acid-grade spar is usually sold in ground form, but some acid lump is also marketed. This grade calls for a minimum of 97.5 to 98 per cent CaF_2 , a maximum of 1 per cent silica, a maximum of 0.03 to 0.05 per cent sulfur, and not over 1 per cent CaCO_3 . Lead and zinc are objectionable impurities.

Ceramic-grade spar is usually ground so that at least 55 per cent will pass through 100 mesh. Standard specifications call for a minimum of 95 per cent CaF_2 , not over $2\frac{1}{2}$ per cent silica, and not over 0.12 per cent Fe_2O_3 . Lower CaF_2 and higher silica are often accepted, but high iron is very objectionable. The spar must be practically free of lead, zinc, and sulfur.

Prices. In the fall of 1950 fluorspar was quoted fob Rosiclare, Ill., as follows:

<i>Metallurgical Grade</i>	<i>Base Price per Short Ton</i>
Effective CaF_2 content:	
70 per cent or more.....	\$37
65 per cent but less than 70 per cent.....	34
60 per cent but less than 65 per cent.....	33
Less than 60 per cent.....	32
Acid grade, 97 per cent CaF_2	43

Utilization. Tables 5 and 6 show the distribution of fluorspar production by grades and by major uses (see also Table 4).

The largest single use for fluorspar is in the steel industry, which accounts for about 50 per cent of the total consumption. Around 5.5 to 6 lb of fluorspar per ton of steel, in basic open-hearth steel practice, is added to the melt just before pouring to increase the fluidity of the slag and aid in the desulfurization of the metal. It is also used in iron foundries, in making electric furnace steel, bessemer steel, and ferroalloys. As a flux, it seems to act mechanically rather than chemically, since a greater part is found unchanged in the slag.

Fluorspar is used as a flux in gold, silver, copper, and lead smelters. It forms fusible compounds with BaSO_4 and CaSO_4 and assists in fluxing zinc as the sulfide or oxide. Fluorspar seems to possess a considerably higher efficiency as a flux than limestone, especially with very siliceous, refractory ores, but only compara-

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TABLE 5. FLUORSPAR SHIPPED FROM MINES IN THE UNITED STATES, 1945 TO 1946, BY GRADES AND INDUSTRIES, SHORT TONS

Grade and industry	1945	1946	Grade and industry	1945	1946
Fluxing gravel and foundry lump:			Ground and flotation concentrates:		
Ferrous.....	184,645*	134,822*	Ferrous.....	6,791*†	5,939*†
Nonferrous.....	1,170	1,410	Nonferrous.....	2,211	2,231
Cement.....	326	661	Glass and enamel.....	35,960	47,377
Miscellaneous.....	158	175	Hydrofluoric acid.....	79,562	78,780
Government stock pile....	7,225	3,907	Miscellaneous.....	1,638	625
	193,524*	140,975*	Government stock pile...	2,224	
Acid lump:			Exported.....	1,420	1,729
Ferrous.....	36	15		129,806*	136,681*
Nonferrous.....	2	2	Total:		
Hydrofluoric acid.....	593	267	Ferrous.....	191,472	140,776
	631	284	Nonferrous.....	3,383	3,643
			Cement.....	326	661
			Glass and enamel.....	35,960	47,377
			Hydrofluoric acid.....	80,155	79,047
			Miscellaneous.....	1,796	800
			Government stock pile...	9,449	3,907
			Exported.....	1,420	1,729
				323,961	277,940

* Fluxing gravel includes (and flotation concentrates exclude) the following quantities of flotation concentrates blended with fluxing gravel: 1945, 4,182 tons; 1946, 9,129 tons.

† Includes pelletized gravel.

TABLE 6. FLUORSPAR SHIPPED FROM MINES IN THE UNITED STATES, 1945 TO 1946, BY USES

Use	1945				1946			
	Quantity		Value		Quantity		Value	
	Per cent of total	Short tons	Total	Average	Per cent of total	Short tons	Total	Average
Steel.....	57.5	186,073	\$5,182,059	\$27.85	48.3	134,295	\$3,843,038	\$28.62
Iron foundry.....	1.1	3,422	94,852	27.72	1.8	4,855	137,507	28.32
Glass.....	10.0	32,300	1,033,737	32.00	14.3	39,837	1,306,005	32.78
Enamel.....	1.1	3,660	128,612	35.14	2.7	7,540	262,530	34.82
Hydrofluoric acid.....	24.7	80,155	2,896,267	36.13	28.5	79,047	3,111,291	39.36
Miscellaneous.....	2.3	7,482	254,560	34.02	2.4	6,730	221,001	32.84
Government stock pile.....	2.9	9,449	260,853	27.61	1.4	3,907	93,800	24.01
	99.6	322,541	\$9,850,940	\$30.54	99.4	276,211	\$8,975,172	\$32.49
Exported.....	0.4	1,420	45,939	32.35	0.6	1,729	63,797	36.90
	100.0	323,961	9,896,879	30.55	100.0	277,940	9,038,969	32.52

tively small percentages can be used effectively, since the favorable effects do not increase in proportion to the quantity added. Fluorspar is used in the refining of copper, in the electrolytic refining of antimony and lead, and in refining lead bullion.

The making of hydrofluoric acid, which took about 28.5 per cent of the total consumption in 1946, is the second largest use and this use is growing rapidly.

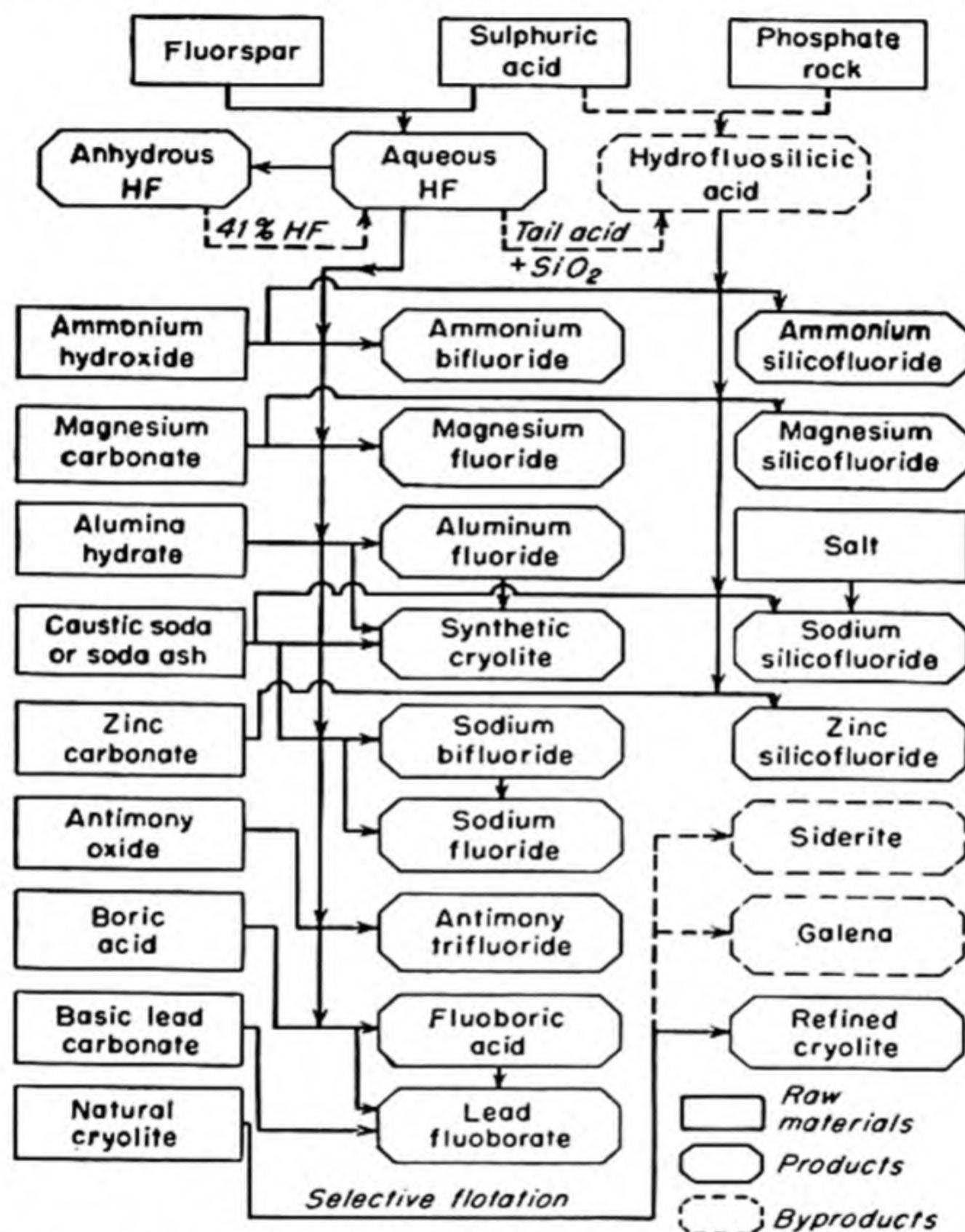


FIG. 7. Fluorine products from fluorspar and phosphate rock.

Hydrofluoric acid is the starting point for making most fluorine chemicals, both organic and inorganic, and fluorine gas. The largest single use for anhydrous hydrofluoric acid has been as a catalyst in alkylation processes for making high-octane gasoline for military aviation. Another large use is for making Freon as a refrigerant and as the propellant for aerosol insecticide bombs. Freon 12 is difluorodichloromethane (CCl₂F₂). Of great technical and probably commercial importance is the development of the fluorocarbons and their derivatives. Work on the Manhattan District project for making atomic bombs greatly stimulated research on fluorocarbons and is resulting in widespread and rapid introduction

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of many new industrial and chemical products. Fluorocarbons are products resembling hydrocarbons in chemical structure, and this new branch of chemistry may become almost as important and diverse as hydrocarbon chemistry.

Inorganic fluorine chemicals are of great and growing importance. Essential to the making of metallic aluminum are cryolite (sodium aluminum fluoride) and aluminum fluoride, which are used in the electrolytic bath in aluminum reduction cells. Artificial cryolite, made from caustic soda, alumina, and anhydrous hydrofluoric acid, is used to supplement natural cryolite (see Cryolite). The making of 1 ton of aluminum requires 6 to 20 lb of aluminum fluoride and 120 to 160 lb of cryolite. The chart from the Pennsylvania Salt Mfg. Co. used by Callahan³ shows the principal inorganic fluorine chemicals and their derivation.

TABLE 7. FLUORSPAR (DOMESTIC AND FOREIGN) CONSUMED AND IN STOCK IN THE UNITED STATES, 1945 TO 1946, BY INDUSTRIES, SHORT TONS

Industry	1945			1946		
	Con- sumption	Stocks at consumers' plants, Dec. 31	In transit to consum- ers' plants, Dec. 31	Con- sumption	Stocks at consumers' plants, Dec. 31	In transit to consum- ers' plants, Dec. 31
Basic open-hearth steel.....	176,488	67,800	5,871	145,631	65,341	3,005
Electric-furnace steel.....	20,873			14,898		
Bessemer steel.....	555			206		
Iron foundry.....	3,877	1,082	51	4,925	1,165	66
Ferroalloys.....	2,909	1,013	.....	2,044	927	.....
Hydrofluoric acid.....	109,315	20,757	506	83,901	17,431	1,810
Primary aluminum.....	1,190	665	.....	1,417	1,182	.....
Primary magnesium.....	811	757	.....		
Glass.....	31,874	5,962	681	39,852	7,136	1,414
Enamel.....	3,695	1,433	101	6,739	1,946	283
Welding rod.....	1,457	257	.....	417	181	.....
Cement.....	365	1,214	.....	608	1,262	.....
Miscellaneous.....	2,681	2,208	12	2,552	2,092	125
	356,090	103,148	7,222	303,190	98,663	6,703

Fluorine from Phosphate Rock. In the chart (Fig. 7) it will be noted that ammonium and magnesium silicofluorides are made from phosphate rock. Phosphate rock contains 2.5 to 3.5 per cent fluorine, which may be recovered in making superphosphates and defluorinated phosphates usually as hydrofluosilicic acid and reacted with bases to make the silicofluorides. But a very small fraction of the available fluorine, however, is now recovered. If all the fluorine from our 1946 production of phosphate rock had been recovered and converted to calcium fluoride it would have about equaled our 1946 consumption of fluorspar. The recovery of this fluorine, except for use as silicofluorides, has not been economically sound due to the difficulty of separating silica from fluorine and the fact that the largest markets have been for the relatively low-priced gravel grades of fluorspar. However, with largely increased use of finely ground fluorspar, higher

prices, advances in our knowledge of fluorine chemistry, and growing exhaustion of our fluorspar reserves, this source of fluorine may become important.

In the summer of 1949 a new Tennessee Valley Authority addition to their Godwin plant, near Columbia, Tenn., started operations that included recovery of fluorine from the stack gases of their two furnaces producing fused tricalcium phosphate. Furnace-stack gases are passed through a tower filled with lump limestone. The hydrogen fluoride reacts with the limestone, forming a film of calcium fluoride that splits off in fine particles from the stone. The calcium fluoride, running 80 to 96 per cent calcium fluoride, is recovered by screening, and the unreacted limestone is recycled. This may become an important development in augmenting our fluorspar resources.

For detailed discussions of the uses of fluorspar and of fluorine chemistry, see Bibliography.^{1,3,7,8,9,14,15,20}

For statistics of United States consumption of fluorspar by industries see Table 7.

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FULLER'S EARTH

General Description. Fuller's earth is an inexact term applied to certain natural clays that have a marked ability to adsorb coloring materials from oils of animal, vegetable, and mineral origin. Most clays have this adsorbing power to a slight or very limited degree and certain other clays, chiefly bentonites, as well as other minerals such as bauxite, can be made highly adsorbent by activation with acids or alkalies, but the term fuller's earth is generally reserved for the naturally highly adsorptive clays. As noted under Bentonite, there has been much confusion in the use of terms by the adsorbent-clay industry. Some clays once called bentonites by producers and so classified by the Bureau of Mines are now known as fuller's earths. The tendency today is to group all clays which are naturally active or which are activable under the general terms "bleaching clays" or "adsorbent clays." (See Nutting's classification of adsorbent clays quoted under Bentonite.)

Composition. In most fuller's earths and practically all activable clays montmorillonite is a dominant if not essential mineral, although there are some naturally active clays in which this mineral is very subordinate or absent. In a few cases beidellite is the dominant mineral. Zeolites are important constituents of some naturally active clays as at Tehachapi, Calif. Small amounts of many other minerals appear as impurities in most clays.

The chemical compositions of several fuller's earths are shown in Table 1.

TABLE 1

	1	2	3	4	5	6
SiO ₂	62.83	54.60	58.66	63.25	56.18	50.61
Al ₂ O ₃	10.35	10.99	17.33	19.25	23.23	19.35
Fe ₂ O ₃	2.45	6.61	7.21	9.14	1.26	3.55
CaO.....	2.43	6.00	3.17	0.82	5.88	1.37
MgO.....	3.12	3.00	3.26	1.65	3.29	3.24
K ₂ O.....	0.74	.....	1.63	2.02	{.....	0.92
Na ₂ O.....	0.20					0.47
SO ₃.....	.....	.....	.....	0.31	.....	.....
H ₂ O*.....	7.72	10.30	8.74	{3.56	11.45	6.45
Moisture†.....	6.41	7.45		{.....	.....	13.73
Total.....	96.25	98.95	100.000	100.00	101.29	99.69

* Combined water.

† Mechanically held moisture.

1. Gadsden County, Fla. C. J. Riederer, analyst.

2. Near Norway, Fla. C. J. Riederer, analyst.

3. Nutfield, Surrey, England. B. Dyer, analyst.

4. Frongoch, near Bala, North Wales. P. G. Sanford, analyst.

5. Fairburn, S.D. Analyst unknown.

6. Wingen, New South Wales, Australia. Analyst unknown.

Physical Properties. Fuller's earth varies greatly in color, the following being common: greenish white, gray, olive, brown, buff, cream, and occasionally almost

* See also Bentonite.

white. It varies from nonplastic to semiplastic, usually but not always disintegrates easily in water, and has a high water content. All fuller's earths of value for bleaching purposes show an acid reaction to litmus. No acid is present, but the earth adsorbs bases in the same way that it adsorbs basic colors.

While the true specific gravity is about the same as that of clay, its apparent specific gravity is often lower due to porosity. Thus, a cubic foot of dry, ground fuller's earth from Georgia or Florida weighs only a little more than half as much as a similar volume of English or Arkansas earth. This is very important in testing, when volumes rather than weights are used, for apparent specific gravities of various dry, ground fuller's earths vary widely.

Occurrence. Fuller's earth deposits vary widely in geologic age, structure, and mode of origin. Authorities differ as to the most common modes of origin. Nutting states: "Apparently all the significant deposits of adsorbent clay were formed from volcanic ash deposited either directly in water or transported and redeposited."⁹ Grim says that "much of the fuller's earth in continental Europe is produced by weathering of basic igneous rocks or is a sedimentary product derived from them."⁴ But Schroter and Campbell say that "given the right conditions, any rock of *favorable composition* (usually siliceous to intermediate) may be altered to bleaching clay of commercial efficiency."¹⁶ Alteration is by acid solutions.

Geographically, fuller's earth has a wide distribution, although the world's needs are satisfied from comparatively few producing localities. England was formerly the largest producer, but today the United States is by far the greatest producer as well as consumer, due chiefly to its very large production of petroleum.

United States. Fuller's earth in the United States was first discovered in 1891 near Benton, Ark., and in 1893 at Quincy, Fla. Until 1924 Florida was the largest producer. From 1924 at least until 1935 Georgia held the leading position. In recent years production statistics for Georgia and Florida have been combined to conceal the totals from each state. Texas production steadily increased until it became the leading producer in 1941 and has continued to hold that position. Illinois is the only other large producer at present.

Texas. The most active deposits of true fuller's earth in Texas in recent years have been in Jasper County, near Brownell, Nacogdoches, and Rockland; near Riverside, Walker County; and between Westpoint and Muldoon, Fayette County. Treatment plants are at Beaumont, Nacogdoches, and at oil refineries.

Georgia and Florida. Near the west half of the Georgia-Florida border are many beds of bleaching clays: some true fuller's earths, some activable bentonites, and some of both types. This belt, centering on a line through Attapulcus, Cairo, and Ochlocknee, contains many deposits of high-grade fuller's earth, 7 to 18 ft thick under light overburden. Practically unlimited quantities of active clays in beds 15 to 20 ft thick occur in the Twiggs formation in Twiggs, Wilkinson, Washington, and Burke counties, Ga.; Dry Branch is an important producing point. Other important producing points are Attapulcus, Decatur County, Ga.; Quincy, Gadsden County, and Ocala, Marion County, Fla. Many other deposits of active or activable clays are known in both states.

Illinois. Most of Illinois production comes from the 60-ft bed of Porters Creek formation clay, mined at Olmstead, Pulaski County, in the extreme southern part of the state.

Other States. Production has come from many other states, and many other promising but undeveloped deposits are known. Some of the present or recent producing areas are near Creede, Colo.; Aurora, Sevier County, and at Ivey, Utah; at Ash Meadows, Nev.; and near Tehachapi, Calif. The so-called fuller's earth at Lancaster and Stoughton, Mass., is a glacial silt with very low bleaching power, but was once used to a small extent for fulling cloth and as a ceramic binder for abrasive grinding wheels. Many other bleaching clays are now classed as activable bentonites.

Great Britain. In England, fuller's earth has been mined at a number of places, but the most important operations are now near Reigate and Nutfield in Surrey, and near Coombe Hay, Midford, and Bath in Somerset. Other deposits occur at Woburn Sands and Apsley Heath, Bedfordshire. A bed of good-quality earth is reported at Rhiwlas, Frongoch, near Bala, North Wales.

In *India*, fuller's earth is produced in small quantities in a number of localities and is used locally for the washing of clothes and as an edible (*sic*) earth. In *Australia*, a deposit of considerable size is reported at Wingen, New South Wales.

Production and Consumption. For many years the United States has been the world's largest producer and consumer of fuller's earth. Once England held that position and our imports from England formed an important part of our consumption. For a variety of reasons imports had become of little importance even before the Second World War. Domestic production increased almost steadily to a peak of over 335,000 tons in 1930, almost in step with our increase in petroleum production, and then sharply declined to a low of about 146,000 tons in 1940. By 1946 it has slowly climbed again to nearly 300,000 tons. This behavior of the production curve obviously departed strongly from the petroleum-refining curve. This decline was due in part to improved petroleum-refining methods and increased use of colored gasolines, and in part to competition from the much more expensive but also much more efficient adsorbents such as the activated bentonites, activated bauxite, and synthetic magnesium silicate. Recovery has been due partly to increased use in oil refining but chiefly to the development of new adsorbent uses, such as for treatment of machine-shop floors. Exports, largely to oil refineries abroad, amounting to nearly 18,000 tons in 1946, have also helped domestic producers. Table 2 shows domestic production in recent years.

Mining and Milling. Most of the deposits of fuller's earth in the United States, consist of sedimentary beds, usually nearly horizontal, covered by a variable thickness of overburden. These beds vary from a few inches to over 25 ft in thickness and are worked by open-pit methods. Usually the beds are stratified and often very thin layers of sand separate layers of earth, which may be several inches thick.

In mining the earth, the overburden is first removed by steam shovel in the larger mines or by wheel scraper, drag scraper, or even by pick and shovel in the smaller mines. In Florida, the maximum thickness of overburden removed is 12

FULLER'S EARTH

to 14 ft, consisting of sand, clay, or even marl. Here the earth is divided into two strata, each 6 to 10 ft thick, by a thin layer of sandy or calcareous material, and usually only the top strata is worked. The earth often breaks out in blocklike forms, which facilitates mining. Upon drying, the interbedded sand tends to fall away, leaving clean, solid blocks of earth. Since fuller's earth readily takes up water, the drainage problem sometimes is serious, for wet earth requires an excess of fuel in later drying operations.

TABLE 2. FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1946 TO 1948, BY STATES

State	1946		1947		1948	
	Short tons	Value	Short tons	Value	Short tons	Value
Florida and Georgia...	144,214	\$2,100,652	168,557	\$2,699,660	188,014	\$3,224,169
Illinois.....	33,134	296,637	37,740	388,955	37,942	410,678
Texas.....	110,693	1,157,892	102,901	1,199,726	92,310	1,162,336
Other states*.....	10,711	147,812	19,870	372,273	23,815	476,668
	298,752	\$3,702,993	329,068	4,660,614	342,081	5,273,851

* Includes California, Nevada, Tennessee, and Utah.

In a few instances steeply dipping beds are mined by underground methods.

At the mill the earth may be first placed in well-ventilated storage bins and allowed to dry, but usually it is fed directly to a crusher, where it is broken into 1- to 2-in. lumps. Preliminary crushing is often done in rolls. Parsons says: "Seemingly the best form of crushers consists of two sets of rolls, one corrugated and one toothed, one above the other."¹⁰ From the rolls the earth is elevated and fed into rotary driers, which in Florida practice are 40 to 60 ft long, about 6 ft in diameter, direct heated and oil fired. The driers may be fired at either the intake or the discharge ends. In some plants the moist earth is run through a brick machine and the bricks, piled on cars, are dried in tunnel kilns heated by hot air.

The bleaching power of some fuller's earths, especially English earths, is reduced or destroyed by heating to a temperature that drives off the combined water. American earths used for petroleum bleaching are not usually impaired by high heat, so that overheating need not be guarded against in drying earth of this type. In drying earths used for edible oils it is sometimes, though not always, necessary to avoid overheating.

The methods used for final grinding vary widely and are dependent upon the physical character of the earth and the nature of the bleaching work for which the earth is intended. For percolation methods of refining, coarse grain size, accurately graded to such sizes as through 15 on 30 mesh, through 30 on 60 mesh, etc., is demanded. For contact methods of refining, the finer the grinding the better the bleaching power, but too fine grinding unduly increases the oil absorption and makes filter pressing difficult. For each earth, therefore, a most advantageous grain size must be found, usually 100 to 120 mesh, with a minimum of very fine

powder. In both types of grinding, therefore, it is necessary to produce a minimum percentage of extremely fine powder. Parsons¹⁰ has emphasized the great importance of selecting the proper grinding methods, for not only may improper methods produce an undue proportion of waste fines, but also a good grade of earth may be rendered almost worthless by improper grinding. The best grain size for each earth and the best method of producing it can only be determined by actual tests.

Since crushing tends to produce few fines and grinding by attrition usually produces a maximum of fines, it follows that rolls, roller mills, hammer mills, and disintegrators are usually to be preferred to emery mills, buhr mills and tube mills. If even rolls give too great a percentage of fines, it is sometimes possible to improve matters by setting the rolls farther apart and returning a greater percentage of oversize from the screens for regrinding.

Whatever the method used for grinding, it is usually necessary to size the finished product by screening or bolting, although earths for edible oils are sometimes marketed without bolting. Screening may be done on inclined, vibrating or impact screens, or in revolving screens or bolting reels covered with wire screen or silk bolting cloth. For petroleum refining, the fuller's earth is passed through a series of screens and divided into several products. For edible-oil refining, the earth is usually passed through a single 100- or 120-mesh screen, the oversize being returned for regrinding. After bolting, the earth is packed in bags for shipment.

The relative proportions of various grades of earth for petroleum refining made at one plant, on a run of 26,270,796 lb of lump earth, are given by Parsons¹⁰ in Table 3.

TABLE 3. PRODUCT OF A MILL ACCORDING TO MESH

Mesh	Output	
	Pounds	Per cent
15-30.....	3,601,260	13.7
30-60.....	10,607,760	40.4
60-80.....	1,576,260	6.0
60 up.....	3,129,906	11.9
100 up.....	1,106,622	4.2
50-180.....	1,380,078	5.25
170 up.....	24,624	0.09
60-110.....	10,044	0.04
Fine waste.....	4,834,242	18.40
Total.....	26,270,796	
Total bagged.....	21,436,554	81.6

Specifications and Tests. The value of a fuller's earth for the clarification of oil can only be determined by actual bleaching tests, and the bleaching power bears no relation to chemical composition. Moreover, an earth that gives good results with one type of oil may be valueless for another type.

For the percolation treatment of mineral oils it is essential that the earth have a

good bleaching power; that it be of proper grain size and not have too great a percentage of fines, so that percolation is not hindered; that it absorb a minimum quantity of oil; and that it be capable of being revived by heat-treatment or other processes. The proper grain size is dependent upon the viscosity of the oil, the temperature at which filtration takes place, and the interplay between plant methods used and the results desired. The sizes most commonly used are through 15 on 30 mesh, through 30 on 60 mesh, and through 60 on 80 mesh.

For the contact treatment of lubricating and edible oils, the requirements are (1) that the earth shall bleach well and that the oil shall not revert to its original color; (2) that it shall filter well and not cake badly; (3) that it shall impart to the oil no permanent, disagreeable taste or odor; (4) that the retention of oil in the spent earth shall be small; (5) that there shall be no spontaneous ignition either in the filter press or in the waste piles. The best grain size must be determined for each earth by actual tests, for the grinding of some earths results in the production of larger proportions of fines than in others. Thus, an English earth may be ground to 120 mesh without an excess of fines, but some American earths can be ground no finer than 100 mesh without producing so many fines as to cause clogging of pores in the filter press. The proportion of fines, as noted previously, is dependent not only upon the nature of the earth but also upon the method of grinding.

In the preliminary testing of a fuller's earth it has been found that all earths that have been found valuable for bleaching purposes show a distinct, so-called "acid reaction." Parsons says:

The degree of "acidity" or adsorptive power for bases in solution in water is no definite criterion of the power of the earth for adsorbing bases or colors from solution in oil. Accordingly, the bleaching power of fuller's earths for oils is by no means proportional to the ability of the earths to remove bases in solution in water. The degree of "acidity" is, however, directly proportional to the power that most fuller's earths have of removing basic colors from solution in water.

All fuller's earths adsorb basic colors in solution in oil or in water. Their commercial value, however, depends upon the power of removing these colors from solution in oil, which, as already pointed out, is by no means the same as removing these colors from water. The power of removing basic colors from water has found application only in the woolen industry and in the production of cheap pigments for paper.¹⁰

A careful laboratory examination of fuller's earth should include a determination of its bleaching power, the rapidity of filtering, retention of oil in the earth, the possibility of revivification, and, in edible-oil earths, whether or not a permanent odor or taste is imparted to the oil. The details of these tests have been described in many places.^{7,9,10}

The practical commercial value of a fuller's earth is arrived at by the balancing of the favorable and unfavorable properties. In the valuation of fuller's earth for the edible-oil industry Richert¹¹ has derived a formula that gives the raw bleaching cost per 100 lb of oil.

Utilization. The original use for fuller's earth was for fulling or removing grease from cloth and for the leveling of colors, but fulling has now been almost entirely superseded by other methods. The principal uses today are for the bleaching and clarifying of oils, fats, greases, and waxes of mineral, vegetable,

and animal origin. Other functions besides the removal of color are improvement of odor and taste from vegetable and animal oils and improvement in sludge content, carbon content, oxidation test, acidity, emulsion test, viscosity index, etc., in lubricating oils. It is used for decolorizing and recovering chemical-plant solvents and dry cleaners' fluids.

Some success has been attained in the use of fuller's earth as a catalyst in the catalytic cracking of petroleum.

It has been suggested and used to a very limited extent for the purification of water in place of activated carbon and for sewage treatment.

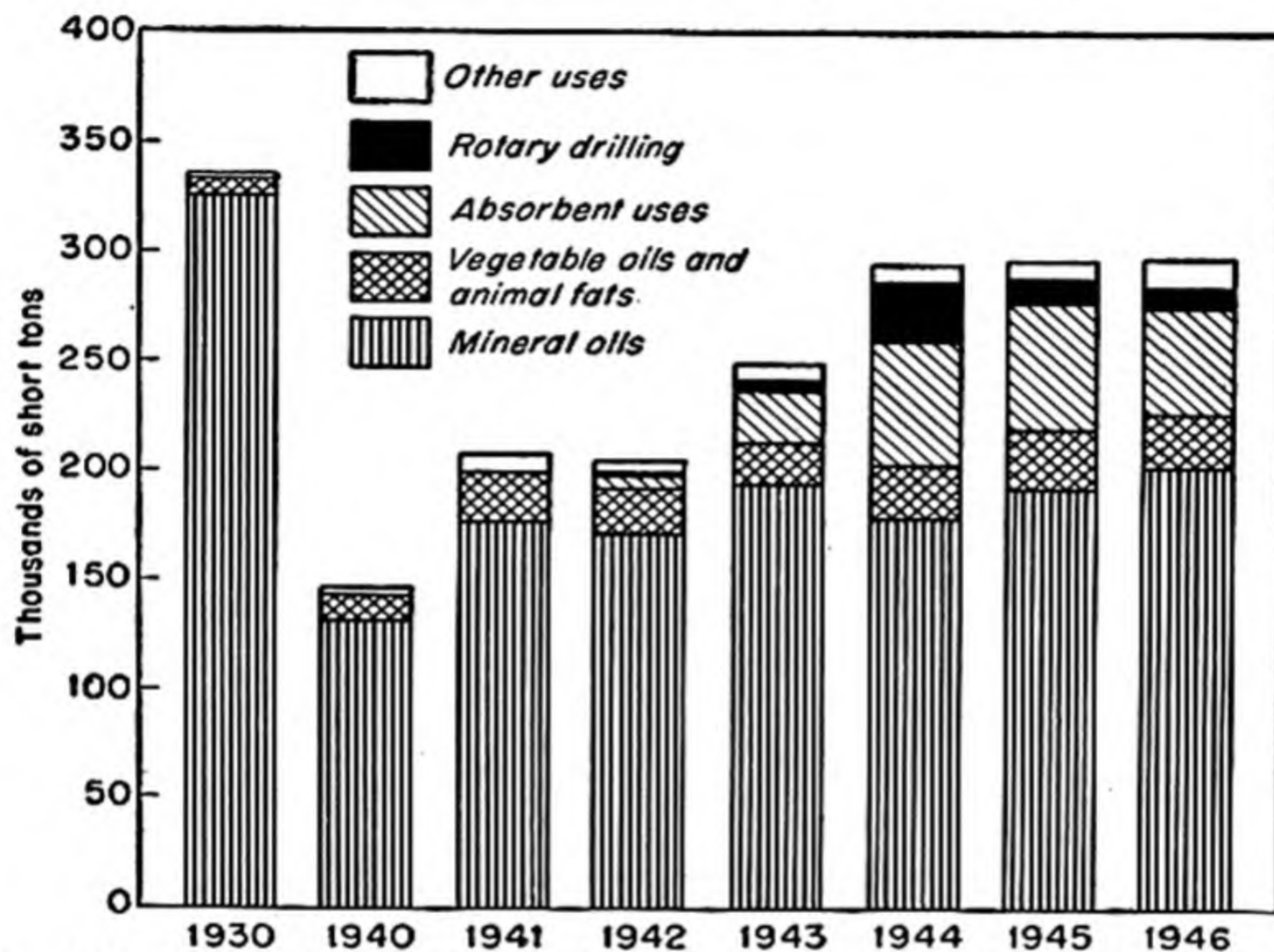


FIG. 8. Fuller's earth sold or used by producers in the United States, 1930 to 1946.

New uses for fuller's earth as an adsorbent, not related to bleaching, have been developed in the past few years and now form important tonnage markets. Its high oil-absorbent and adsorbent properties have made it of great value as a floor-treatment material in machine shops and garages. Not only does it absorb free surface oil, but it also draws accumulated oil out of the floor by capillary action, making a nonskid floor, lowering fire hazards, and increasing light reflectivity.

A relatively small tonnage is used for oil-well drilling muds.

The distribution of production by uses in recent years is shown in the chart (Fig. 8) from the Bureau of Mines.

The problem of waste fines has been solved, for some clays at least, by moistening them with water, kneading them in a pugmill, and extruding the stiff dough through slots or dies to form "spaghetti," from $\frac{1}{4}$ to 1 in. in diameter. The product is then dried, granulated, and screened into the desired size of granules. With a relatively dry water-clay mix, friction in the dies produces innumerable

fine cracks in the product, thus resulting in a more porous structure than in the granules made from the original clay. The bleaching efficiency of some clays is thereby increased as much as 20 per cent.

The finished products may be shipped in bulk in box- or tank cars or in paper or burlap bags.

Prices. Since it is easier to make pulverized fines than coarse granules and since fines may be a waste product, prices on fines are usually considerably below prices on granules. Prices on activated bentonites are much higher than on naturally active fuller's earth, but the higher prices are justified by both higher costs of production and much greater bleaching efficiency.

In 1950 fuller's earth was quoted in Georgia and Florida, fob cars, at \$14.50 per ton for material sized from 30 to 60 mesh, and at \$14 for material 15 to 30 mesh. Fines, 200 mesh and up, were quoted at \$10 per ton; 100 mesh and up, \$7.

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GARNET

Composition. Garnet is a name given to a group of minerals of similar physical properties and crystal habit. The composition of this group is expressed by the general formula $M^{++}_3M^{+++}_2(SiO_4)_3$, in which M^{++} represents any of the bivalent metals; magnesium, calcium, manganese, or ferrous iron; and M^{+++} a trivalent metal: aluminum, ferric iron, or chromium. At least seven distinct species have been recognized in this series. They are:

<i>Name</i>	<i>Formula</i>
Grossularite.....	$Ca_3Al_2(SiO_4)_3$
Pyrope.....	$Mg_3Al_2(SiO_4)_3$
Rhodolite.....	$2Mg_3Al_2(SiO_4)_3 \cdot Fe_3Al_2(SiO_4)_3$
Almandite.....	$Fe_3Al_2(SiO_4)_3$
Spessartite.....	$Mn_3Al_2(SiO_4)_3$
Andradite.....	$Ca_3Fe_2(SiO_4)_3$
Uvarovite.....	$Ca_3Cr_2(SiO_4)_3$

Cinnamon stone is a common name for grossularite.

Hessonite (or *essonite*) is a variety of grossularite.

Topazolite is a yellowish or greenish variety of andradite.

Demantoid is a grass-green variety.

Melanite is a a black variety of this garnet.

Rothoffite $[(Ca,Mg)_3Fe_2(SiO_4)_3]$ is a variety of andradite, usually high in manganese.

Colophonite is another variety of andradite.

(The last two varieties are associated with wollastonite in Essex County, N.Y.)

A garnet may contain almost any of the elements listed as long as a ratio of 3:2 is preserved between the bivalent and trivalent members. The composition may become complex and one variety grade over into another. Physical properties will display similar variation.

General Description. Garnets are usually found well crystallized in the cubic system, the principal forms being rhombic dodecahedrons, tetragonal trisoctahedrons or combinations of the two, and hexoctahedrons. They also occur as rounded disseminated glassy grains and in compact massive, laminated or granular aggregates. They vary greatly in color, but the most common garnets, almandite and andradite, are most often found in a dark-red or reddish-brown color.

Physical Properties. *Hardness*, 6.5 to 7.5. *Specific gravity*, 3.4 to 4.3. *Melting point*, almandite, 1313 to 1318°C. *Index of refraction*, pyrope (pure mineral), 1.705 to 1.742; grossularite (pure), 1.735; rhodolite, 1.760; hessonite, 1.763;

GARNET

almandite (pure mineral), 1.778 to 1.830; spessartite (pure mineral), 1.800 to 1.811; uvarovite, 1.838; andradite (pure mineral), 1.865 to 1.895; melanite, 1.94.

Some garnets, particularly the andradite variety from contact metamorphic zones, may be birefringent. Such garnets invert when heated to about 800°C to a normal isotropic form.

Color, grossularite, white, yellow, cinnamon brown, rose red, green, and colorless; pyrope, deep red to nearly black; spessartite, brownish red to hyacinth red; almandite, deep red to brownish red, or black; uvarovite, emerald green; andradite, brownish red, brown, dark gray, black, also shades of yellow and green.

Composition. The composition of some commercial garnets is indicated by the following analyses:

Component	North Creek, N.Y.	Wevertown, N.Y.	Jackson County, N.C.	Mirrimack County, N.H.	Almeria, Spain
SiO ₂	40.24	38.92	38.52	37.39	37.06
Al ₂ O ₃	20.06	22.77	21.53	20.46	26.92
Fe ₂ O ₃	4.65	1.80	2.72	2.89	0.00
FeO.....	18.58	23.34	27.75	31.87	32.24
CaO.....	5.34	5.22	2.03	0.92	1.02
MgO.....	11.18	7.09	8.28	2.46	1.86
MnO.....	0.25	0.15	0.12	3.47	2.93
	100.30	99.29	100.95	99.46	102.03

Occurrence. Geologically, garnet is found in greatest abundance in crystalline schists and gneisses, but it also occurs in pegmatites, as a contact metamorphic mineral, especially in crystalline limestones, in serpentines and peridotites, and in various types of igneous rock. It also frequently occurs as rounded grains in stream and sea sands.

Few deposits of garnet of commercial importance have been developed or even reported upon, due probably more to the small demand than to scarcity of deposits. Aside from its use as an abrasive, which has not been large, garnet has been valuable only as a semiprecious gem stone and as jewels for cheap watches.

While nearly all types of garnet are sometimes used for gem stones when found sufficiently clear and transparent, only two types have been found of value for abrasive purposes. These are almandite, or red garnet, and rhodolite, a hard pink garnet found only in North Carolina. Statistics of production of abrasive garnet are available only for the United States, but Spain produces a small amount, and it is probable that some other countries produce on a small scale for local use.

United States. The principal and practically the only important garnet-producing state now is New York, but New Hampshire, North Carolina, Pennsylvania, and Connecticut have produced small quantities in the past.

In *New York*, garnet deposits are known in Warren, Essex, and St. Lawrence counties. The principal mine at present is the Rogers mine, owned by the Barton Mines Corp. in Warren County about 4½ miles south of North River village,

near the top of Gore Mountain. The rock here is not a gneiss, but a dark-gray, massive, granular, porphyritic rock without banding or schistosity, consisting largely of hornblende and feldspar with garnet nodules. This rock occurs as a long, narrow band enclosed in gneiss. The garnet nodules are single individual crystals of imperfect form, varying from 2 in. to 3 ft in diameter, surrounded by shells of hornblende. The garnets, which are laminated or divided into thin plates by a system of parallel parting planes, occur roughly bunched in pockets. At the surface the enclosing rock is decomposed so that mining is easy.

The Hooper mine, near Thirteenth Lake about $3\frac{1}{4}$ miles southwest of North River village, Warren County, was operated by the North River Garnet Co. The ore is a garnetiferous gneiss containing almandite garnet in grains from a small fraction of an inch to 4 or 5 in. in diameter, averaging less than 1 in. The average garnet content of the rock is probably about 7 to 8 per cent or even less. The deposit is said to be very large.

The Sanders Brothers deposit near Wevertown, on the north side of Mill Creek, about $1\frac{3}{4}$ miles south of Riparius, Warren County, has been operated on a small scale in recent years by the Warren County Garnet Mills. The ore here is a rather narrow band, consisting of a light-red garnet of granular habit intermixed with a green pyroxene in a country rock of fine-grained gneiss. In places the garnet is concentrated so that it forms nearly the whole rock mass. The garnet shows no parting but breaks into irregular grains.

The Crehore mine, located in Essex County, about 5 miles northwest of North River village, has been worked in recent years by the American Glue Company. The garnet occurs in a band of hornblende gneiss with an exposed width of about 40 ft. Garnet crystals running up to 6 or 8 in. of maximum diameter are found in a black hornblende matrix, a type of rock resembling that at Gore Mountain.

Other deposits, some of which have been worked in the past, occur on Oven Mountain, 4 miles south of North Creek; a few miles south of Keeseville, Essex County; at the Rexford mine, $1\frac{1}{3}$ miles south of North Creek; at the Parker mine, just southwest of Dagget Pond and $4\frac{1}{2}$ miles northwest of Warrensburg, Warren County; at the Amasa Corbin mine 3 miles north of Gouverneur, St. Lawrence County.

New Hampshire. In New Hampshire, the only garnet-producing locality is in Merrimack County near North Wilmot. Here almandite garnet occurs as small crystals up to $\frac{3}{4}$ in. in diameter (average $\frac{1}{4}$ to $\frac{3}{8}$ in.) in a matrix consisting of biotite, quartz, and albite feldspar. The richest rock is probably about two-thirds garnet, but the average is much less. The garnet crystals are somewhat rounded and contain included quartz and biotite, so that fine crushing is necessary to effect a clean separation.

North Carolina. Large deposits of abrasive garnet, both almandite and rhodolite, are known in North Carolina, but production has never been large and in recent years mining has practically ceased. Garnet has been mined or is known to exist in important quantities in Clay, Jackson, Macon, Madison, and Burke counties. Probably the largest deposits are those of almandite garnet in Clay County and of rhodolite or pink garnet in Jackson County.

At Penland Bald on Buck Creek, Clay County, near the Macon County line, is

a very large deposit of garnetiferous hornblende gneiss. Here almandite crystals up to $2\frac{1}{2}$ in. in diameter form perhaps 3 to 25 per cent of the total rock mass, 10 per cent being an average amount. A similar deposit occurs on Shooting Creek, east of Hayesville, Clay County. It is evident that very large reserves of high-grade abrasive garnet exist here, but development has been hindered because the deposits occur in rugged, more or less inaccessible country, 7 to 11 miles from the nearest railroad.

A very large deposit of rhodolite or pink garnet occurs on Doubletop and Sugar Loaf Mountains about $2\frac{1}{2}$ miles south of Willets, Jackson County, close to a timber railroad connecting with the Southern Railway at Willetts. This deposit consists of a quartz biotite gneiss containing 25 to 50 per cent rhodolite in the form of disseminated crystals up to $\frac{3}{4}$ in. or more in diameter. A small mill was equipped here a number of years ago and a small tonnage shipped, but it has not produced in recent years. The reserves here are so large, the grade of the ore is so high, the accessibility of the deposit is so good, that this deposit undoubtedly will sooner or later be of commercial importance.

A deposit of almandite garnet was once worked on Little Pine Creek, near Marshall, Madison County. Here the garnet occurs as large crystals averaging from 2 to 6 in. in diameter in a band of chloritic schist 20 ft wide, which is traceable for over a mile. The garnet near the surface is slightly chloritized, but deeper down it is fresh, clean, and sharp and easily separated from the rock. Other deposits of almandite and rhodolite have been reported in this state.

Some garnet has been recovered as a by-product of the milling and concentration of cyanite ores.

Connecticut. Garnet occurs in Connecticut near Roxbury and Roxbury Falls, Litchfield County, and these deposits were once, though not recently, worked for abrasive garnet. Here the garnet, close to andradite in type, occurs in mica schist as dodecahedral crystals from less than $\frac{1}{4}$ to nearly 2 in. in diameter (average about $\frac{3}{4}$ in.). The crystals are well formed and separate easily from the schist. The deposits were worked mainly to furnish garnet for the shoe-finishing trade.

Idaho. Garnet sands have been recovered by three firms from the stream beds in western Idaho near Fernwood. Information as to the extent of reserves and the type of garnet is not available.

Pennsylvania. Garnet deposits are known at several places in Delaware and Chester counties, Pa., and were worked quite actively before 1900, but have not produced in recent years. Mining operations about 1 mile west of Chelsea, Delaware County, seem to have been the most important. Here almandite garnet occurs, impregnating a quartzose mica schist, and constituting in places nearly 75 per cent of the rock mass. Near the surface the rock was disintegrated and the garnet was easily separated, but about 20 ft down the rock became so hard that the garnets were broken in freeing them from the rock mass.

Near Chester Heights, Delaware County, a small quantity of garnet was once mined by tunneling and shaft-sinking in a badly decomposed gneiss. The garnet of the almandite type occurred as small trapezohedral crystals thickly scattered through the rock.

Georgia. A deposit of garnet of about the pyrope type is reported near Dahlonega, Lumpkin County, Ga., about 1 mile south of Porter Springs. The garnet occurs in schists, in small crystals often so coated from weathering that they are valueless for abrasive purposes. This deposit has never been worked, and it seems unlikely that it would be of commercial interest, since pyrope is usually not of sufficient hardness.

Virginia. In Nelson County, Va., about 4 miles south of Arrington, an attempt was once made to mine garnet from the high steep bluffs on the northeast side of the Tyl River. Here a dull-red garnet in crystals of small but variable size is irregularly distributed through a sericitic schist. No commercial production was ever attained.

Spain. A relatively small amount of abrasive garnet is produced annually in the province of Almeria in Spain. The garnet occurs as small rounded grains mixed with sand in stream placer deposits. Owing to the small size of the grains and their rounded nature, this garnet is considered of inferior quality and will not furnish the full range of sizes required. In 1914, this garnet was worth \$7.75 at the mines and, with \$6.65 freight to seaboard, it could be laid down in the United States at \$20 per ton. There has been in the past small demand for garnet in Europe and most of the Spanish garnet was shipped to the United States.

Labrador. A garnet deposit is reported in Labrador at St. Michael's Bay, 35 miles north of Belle Isle, on an island about a mile long by half a mile wide. It is stated that the garnet is associated with quartz and mica in a ledge 11 ft wide exposed for 330 ft in length. It has been tested for abrasive purposes and found to be of good quality.

Production and Consumption. No statistics of production of abrasive garnet in countries other than the United States are available nor are import or export statistics available for this country. Thus, it is impossible to obtain an accurate estimate of the world production. It is improbable, however, that important quantities of garnet are produced outside the United States except in Spain. It is also probable that the Spanish production has been rarely, if ever, over 2,500 tons per year, and most of this garnet is shipped to the United States.

Some garnet is exported from this country, but probably only a few hundred tons per year. The accompanying table, from the U.S. Bureau of Mines, shows garnet production and its value.

ABRASIVE GARNET SOLD OR USED BY PRODUCERS IN THE UNITED STATES

Year	Short tons	Value
1940	4,716	\$259,345
1941	5,501	371,752
1942	4,357	299,904
1943	5,935	429,120
1944	*	*
1945	6,306	375,198
1946	7,743	570,186
1947	8,722	614,071
1948	8,039	587,797

* Not published.

Mining and Milling. The mining of garnet has always been done on a small scale, and simple hand methods have largely been used. At one time a small amount of garnet was obtained in Pennsylvania by underground mining, but practically all garnet mining is open-cut work.

For a time, during the period of its active operation, the quarry and mill of the North River Garnet Co. near Thirteenth Lake, Warren County, N.Y., was the largest garnet producer. The quarry was operated by small benches, and large blocks of ore were reduced by secondary blasting. The broken rock, containing from 4 to 8 per cent garnet, was transported to the mill where it was crushed and screened, and the valuable garnet separated from its worthless associates by the use of jigs and tables. The final concentrate was dried and sacked for shipment.

The largest producer of garnet is the Barton Mines Corp., operating on Gore Mountain near North Creek, N.Y. The ore body consists of a metamorphosed igneous rock of unknown genesis containing about 40 per cent hornblende; the remainder consists of feldspar, pyroxene, biotite, and small amounts of magnetite, pyrite, and ilmenite. The garnet, which forms from 10 to 12 per cent of the rock, occurs in large crystals, up to a maximum approaching 30 in. in diameter. The garnet masses frequently are single crystals, rhombic dodecahedral in form. The ore body has been traced for $\frac{3}{4}$ mile and varies in width from 50 to 300 ft. The garnet crystals generally are surrounded by rims of nearly pure hornblende. The garnet has a specific gravity of 3.8 to 4.1, and the hornblende 3.07 to 3.24. The separation of these two minerals is the most difficult problem involved in concentration.

Until 1923 mining was carried on in the soft oxidized zone, which existed to a depth of some 15 ft. The garnet in this zone exhibited great stability and few signs of alteration, although the surrounding minerals had been kaolinized and otherwise changed until unrecognizable. In 1923 the first mill was constructed. This was redesigned in 1928. Briefly it consisted of crushing, screening, and concentration in James and Hooper vanning jigs to produce a clean concentrate running over 90 per cent garnet. In 1937 interest was aroused in heavy-media separation and experiments were conducted that led to the adoption of this method in 1941. As described by Vogel^{10,10a} the ore is now crushed and screened, and the bulk of the concentration carried on, originally in a cone, later in an Akins spiral separator using ferrosilicon as a heavy medium. The ferrosilicon is sized, 100 per cent -65 mesh and 96 per cent -100 mesh. A controlled suspension of this heavy material in water permits the establishment of a heavy liquid having such a gravity as to allow the heavy material to sink while the lighter is floated and removed. Top gravity is checked at 15-min intervals and maintained from 3.10 to 3.25. Bottom gravity is about five-hundredths higher. Jigs are used in a minor role for cleaning. This is reported to be the first use of ferrosilicon heavy-media in the nonmetallic industries and the first use except for the treatment of iron ores. The process permits an increased recovery and economy in operation.

Marketing, Shipping, and Prices. The producers of abrasive garnet customarily ship their product as garnet concentrate rather than as finished grains graded to final sizes ready for use. The usual reason given for this, as has been

stated, is that most manufacturers of garnet paper and cloth have their own individual standards of grain sizes, which differ slightly from those of their competitors. Much garnet sized and graded by producers is resized by the purchaser. Most coated-abrasive manufacturers have crushing, grinding, and screening equipment. The crude concentrated garnet is packed in bags weighing 100 to 150 lb each and sold at a price per net ton, fob shipping point. Adirondack concentrates were quoted at \$85 per ton in the early part of 1950.

Specifications and Tests. The commercial value of abrasive garnet depends upon its hardness, toughness, cleavage or fracture, and purity. There are no standard specifications and tests for abrasive garnet, and actual use is the only adequate means of valuation. Certain minimum requirements, however, must be met before further testing is justified. While the hardness ordinarily attributed to garnet varies from 6.5 to 7.5, the best types of abrasive garnet have a hardness of nearly 8.0. For the garnet to be of value, therefore, the hardness should be at least 7.5. The grains, crystals, or masses should be large enough so that when crushed and screened they will yield sharp, angular grains in a full range of sizes (20 to 200 mesh or 0.034 to 0.0029 in.). A rock containing garnet of only very small grains is of no commercial value, no matter how great the garnet content is. Granular garnet is usually not of great value, for it breaks into rounded rather than angular grains. Garnet sand, unless very coarse, is of low value, for it does not usually yield a full range of sizes and the crushed grains have one or more rounded faces. Massive, laminated garnet that breaks in long scale-shaped grains is ordinarily considered to be the best type. In crushing, small grains produce more waste in fines than do large grains and masses. Good abrasive garnet should be fresh, that is, not altered or weathered, and it should contain no impurities. Cleavage should not be too well developed or the grains will not have the requisite toughness.

The color of garnet by itself probably is of little importance as an index of its value as an abrasive, although the red or pink varieties (almandite and rhodolite) are the only ones that have been used successfully to date. There is a prejudice in the trade against pink garnet, however, due probably to the generally poorer quality of the pink Spanish garnet (partly due to origin) and to a few shipments of impure, weathered, pink rhodolite from North Carolina. Experienced garnet users claim that the unweathered rhodolite garnet is equal to the best Adirondack almandite garnet. One large consumer of garnet states that the deep claret-colored varieties of garnet from the pocket-type deposits of the Adirondacks are the best, Spanish garnet slightly inferior, and New Hampshire and Connecticut garnet considerably poorer. In the finer grain sizes the differences between the Spanish and the best Adirondack garnet are usually small. In the coarser sizes Spanish garnet is reported to be possibly 10 per cent less efficient than the New York laminated garnet, and it is usually mixed with the latter type.

Utilization. Attractive colored garnets have been used as a semiprecious gem stone for centuries. The fiery-red pyrope mined in Bohemia is perhaps the best known variety. Deep red almandites, cut cabochon, have been sold extensively under the name "carbuncle." The green, fine-textured uvarovite of the Transvaal has been substituted for jade. A limited amount has been used for jewels in

watches. Garnet grain has been used for polishing glass, stone, and similar products. It is doubtful that the total amount consumed amounted to more than 5 or 6 per cent of the annual total in any one year. The most important consumer is the manufacture of surface-coated abrasives.

In the manufacture of coated abrasives, such as a garnet paper or cloth, the backing is either paper or cotton cloth of various weights, or else a combination of paper and light cotton cloth glued together. For the best grades of coated paper abrasives, manila fiber paper is used, but kraft-paper backing is usually used for cheaper coated abrasive products, such as flint paper and emery paper. Cotton cloth must first be treated to fill the pores. The backing is then fed from large rolls through a rotary press that prints the grit number, etc., at regular intervals on the back of the sheet. It then passes between two rolls, one of which runs in a trough of glue and spreads a coating on the backing; then under a reciprocating brush, which spreads and smooths out the glue; thence under a grit hopper, from which a steady stream of abrasive grain pours. The grain must be sized with great accuracy within very narrow limits. The paper or cloth is then fed in great loops upon drying racks. From the drying racks it passes through a sizing machine in which a second coating of glue is added to anchor the grains firmly in place; thence to the final drying racks, and finally to a winding machine. The coated abrasive is wound in rolls of about 1,000 yd, varying in width from 22 to 48 in. From these rolls it is cut up into standard-sized sheets (9 by 11 in.) or into 50-yd rolls of varying widths, or it is made up into belts or disks.

The amount of abrasive used per unit of area depends upon the strength of the glue solution, type of abrasive, character of backing, and size of grain. High-grade hide glue is used almost exclusively. The bulk of the coated garnet abrasives is used in the form of belts or as covers for drums or drum sanders. A small proportion is also used in disk form, and quite an appreciable percentage in the form of sheet goods for hand use.

Garnet-coated abrasives are used most widely in the woodworking industries, but they are also used in smoothing and abrading leather, rubber, and metals; in rubbing down or removing paint and varnish; and in many other minor ways. In wood-finishing operations, such as in furniture factories, most of the surfacing is done on various types of drum and belt "sanding" machines, but disk "sanders" are also used.

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GIBBSITE

Composition. Gibbsite is aluminum hydroxide, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ or $\text{Al}(\text{OH})_3$; Al_2O_3 , 65.35 per cent; H_2O , 34.65 per cent.

General Description. Gibbsite is an earthy white or nearly white mineral, usually occurring in thin mammillary crusts or foliated, massive, or fibrous masses; sometimes stalactitic; rarely in monoclinic crystals. It is a major constituent of some bauxites and a minor one of others.

Physical Properties. *Hardness*, 2.5 to 3.5. *Specific gravity*, 2.40. *Index of refraction*, 1.566 to 1.587. *Color*, white or in grayish, greenish, or reddish shades. *Streak*, white. *Luster*, vitreous, pearly, or dull. *Cleavage*, basal; brittle. *Transparency*, transparent to opaque.

Occurrence. Gibbsite is a common secondary mineral produced by the weathering of mineral with a high alumina content, such as corundum, nepheline, or the feldspars. It is also found as the product of hydrothermal alteration in igneous rocks, at times along the contacts of veins that may be ore-bearing and therefore exposed by mining operations. Crystals, several inches in length, have been found in cavities in rocks in the Urals. It is a characteristic mineral in laterites and bauxite. It is found in bauxites in Arkansas and Georgia, and has been identified in small quantities in Massachusetts and New York. Nearly pure gibbsite occurs in nodules, up to several feet across, in the Salem Hills area of Polk and Marion counties, Ore. These deposits may be of interest for local, small-scale chemical or refractory use.² It has a wide distribution geologically and geographically.

Utilization. Gibbsite is usually not found in sufficient tonnage and purity to be mined separately and to establish uses connected with its identity. It supplies much of the alumina found in bauxite and therefore becomes indirectly an important source of aluminum and its salts. According to Allen¹ gibbsite is detri-

mental in clays employed as fillers in the paper industry, but of value in clays used in the ceramic industries, since gibbsite adds to the refractoriness of the clays.

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GRAPHITE

Composition. Graphite (also known as plumbago or black lead) is elemental carbon (C) often mixed with greater or fewer impurities. Analyses of typical commercial graphites are given in Table 1.

TABLE 1. ANALYSES OF SAMPLES OF CRUCIBLE GRAPHITE*

	Source of graphite						
	Alabama				New York	Pennsylvania	Ceylon
Sample No.....	1	2	3	4	5	6	7
Volatile carbon.....	2.08	1.40	2.66	1.31	1.30	1.53	1.68
Graphitic carbon.....	84.52	90.58	81.82	91.18	88.97	88.80	85.06
SiO ₂	7.02	3.99	8.33	4.08	4.34	5.24	7.81
Al ₂ O ₃	5.06	2.96	6.35	2.31	2.40	2.05	2.82
Fe ₂ O ₃	0.53	0.18	0.39	0.40	1.08	1.75	1.61
TiO ₂	0.14	0.19	0.13	0.13	0.38	0.05	0.13
CaO.....	.....	.....	.....	.....	0.07	.....	0.19
MgO.....	0.23	0.16	0.06	0.08	0.76	0.09	0.21
K ₂ O.....	0.15	0.23	0.14	0.31	0.55	0.08	0.25
Na ₂ O.....	0.008	0.01	0.11	0.03	0.12	0.12	0.11
SO ₃	0.007	0.14	.....	0.01	.....	0.21	0.005
P ₂ O ₅	0.06	.....	.....	0.02	0.02	0.05	0.05
MnO.....	.....	.....	.....	.....	.....	0.07	0.04
ZnO†.....	.....	.....	.....	.....	.....	.....	0.03
CuO ₂.....	.....	0.14	.....	.....	.....	.....	.....
Total.....	99.805	99.98	99.99	99.86	99.99	100.04	99.995

* DUB, G. D. and MOSES, F. G., Mining and Preparing Domestic Graphite for Crucible Use, *U.S. Bur. Mines, Bull.* 112, 1920, p. 40.

† Contamination probably from brass screens.

General Description. Graphite is a very soft, black, greasy-feeling mineral occurring in disseminated flakes or in scaly, granular, compact, or earthy masses. When impure it may be dull and slaty or earthy. The term "crystalline graphite" or "flake graphite" refers to the varieties that occur in crystals large enough to be visible to the unaided eye. It occurs both massive in veins (often called plumbago) and in flakes disseminated through the country rock.

The finely granular variety, known as "amorphous" in the trade, is not really amorphous but cryptocrystalline.

Physical Properties. *Hardness*, 1 to 2. *Specific gravity*, 1.9 to 2.3. *Melting point*, probably above 3000°C, but at high temperatures gradually burns. *Color*, black or very dark gray. *Streak*, dark gray or shiny black. *Luster*, metallic to dull or earthy. *Cleavage*, perfect basal. *Fracture*, irregular. *Transparency*, opaque (transparent to X-rays). *Tenacity*, scales flexible, slightly sectile. *Feel*, greasy, unctuous. Marks paper. *Insoluble* in acids. Good conductor of electricity.

Occurrence. Commercial graphite deposits are of several types. Graphite results from the alteration of carbonaceous matter in sediments—for example, the flake or crystallized graphite of Alabama and Pennsylvania. Graphite resulting from the intrusion of igneous rocks may be of organic origin, as in the altered coal beds at Raton, N.Mex.; Sonora, Mexico; Styria, and Austria; or it may be due to igneous emanations, as in the graphite deposits of Quebec. Graphite also occurs in dikes and veins in igneous sedimentary and metamorphic rocks, such as granites, gneisses, mica schists, and crystalline limestones. The origin of such deposits is obscure.

Graphite is very widely distributed geographically and is produced in important quantities in at least 14 countries. However, a large proportion of the production in many countries is of low-grade, amorphous graphite largely consumed locally. In tonnage Korea is the world's largest producer of graphite (with the possible exception of Russia), followed, more or less in order of production, by Germany (Bavaria), Austria, Madagascar, Ceylon, and Mexico. But, as Tyler¹⁹ notes, while Madagascar and Ceylon together may produce only 15 per cent of the world's tonnage, the combined value is probably at least half the world's total. The most essential and most valuable type of graphite in world commerce is high-grade flake graphite suitable for crucible use. During the early years of the Second World War it was the lack of crucible-grade graphite from Madagascar and Ceylon that threatened to endanger our war program. Any consideration of world resources of graphite must make the vital distinction between crucible flake and all other varieties.

Madagascar is the leading producer of high-grade flake graphite, taking the position formerly held by Ceylon. Deposits in the east central part of the island are extensive and of high grade. The graphite occurs in flakes, lenses, veins, pockets, and large masses in schists and gneisses, in deposits scattered over a distance of 400 miles.¹⁵ Van Slaars²¹ states that the average yield is 1 ton of 50 per cent carbon rough concentrates to 3 tons of ore and that 4½ tons of rough concentrates yield 1 ton of standard, 90 per cent carbon flake and 1 ton of dust with 80 to 86 per cent carbon. All products are exported (from the port of Tamatave) as there are no domestic markets.

Ceylon^{3,6} produces both lump and flake graphite, although the latter is scarce. Producing deposits have been centered in the southwestern part of the island but favorable formations are more widely scattered. The graphite occurs in seams and veins up to 6 ft wide, cutting both igneous and sedimentary rocks. Deposits are worked as open pits or as underground mines to a maximum depth of 400 to 500 ft. Ceylon is the only large producer of high-grade lump graphite. The ore mined, containing as much as 50 per cent of impurities, is first hand-sorted to from 5 to 10 per cent impurities, then transported to Colombo or Galle for further treatment, known as "curing." This process consists of sorting high-grade lump, screening the ordinary grades, further sorting, crushing, screening again, washing low-grade ore by "panning" in tubs, and blending to make different grades. The finished products are packed in wooden casks for shipment.

Over 20 grades of flake, lump, chips and dust are made, with carbon content ranging from 55 to 98 per cent.

Germany.¹⁴ There is but one graphite district of importance in Germany. This is near Passau in eastern Bavaria, near the Austrian border. Here occur lenses of flake graphite in gneisses 10 to 20 m thick; the normal graphite content is 20 to 25 per cent, and the probable workable depth of deposits (due to deep weathering) is about 70 m. The ore is concentrated to products running 82 to 92 per cent carbon, which are sold for nearly all types of uses. Before the war, however, Germany imported important quantities of graphite from Madagascar and Ceylon, at the same time exporting to Great Britain, Scandinavia, and the United States.

Czechoslovakia deposits, in Bohemia and Moravia, are extensions of those in Bavaria. Production, once large, has declined since 1930.

Austria. The Austrian deposits are similar to those of Czechoslovakia and Bavaria. Before the dismemberment of Austria after the First World War this country was the world's largest producer of graphite, and through both World Wars Austrian deposits supplied Germany with this critical mineral.

Korea. Most of the graphite mined in Korea is of the amorphous variety, but some crystalline flake is also produced. Japan has been the principal user of Korean graphite, and the surplus was exported through Japan before the last war. This graphite is used largely for foundry facings, paint, and other noncritical uses.

Mexico. High-grade amorphous graphite is mined in central Sonora from deposits that have been judged as perhaps the largest in the world. The graphite occurs in beds up to 24 ft thick in metamorphosed sandstone and were probably formed by the metamorphism of coal beds. The main vein averages 80 per cent graphitic carbon and ranges up to 95 per cent. Properties are largely American owned, and the crude ore is shipped to Saginaw, Mich., for refining. Formerly it was used chiefly for making lead pencils, but it is now also used for foundry facings, dry batteries, and other uses.

Russia is known to have considerable graphite resources. Just before the Second World War she was credited with over 40 per cent of the world's production, but little information is available as to the deposits.

The *United States* has never been self-sufficient in high-grade crystalline graphite for crucible use. In normal times the use of graphite crucibles has been

declining, and graphite has been considered as a relatively unimportant minor mineral. But in wartime this use increases greatly, and early in the Second World War, when our supplies from Madagascar and Ceylon were cut off, the shortage of crucible graphite became very serious. Strenuous efforts were made by the government to increase our production, and financial assistance was given to five companies for building or rebuilding plants, two at Ashland and one at Goodwater, Ala., and one each at Burnet, Texas, and West Chester, Pa. No plant was able to produce graphite equal to Madagascar flake in quality, although some useful production resulted, and after the shortage was eased most of the plants closed down. One plant in Alabama^{5,10} and that at Burnet, Tex.,¹¹ have managed to survive, producing some crucible flake along with finer sizes for lubricants, foundry facings, paint, etc.

Crystalline flake graphite has been mined in fair quantity from time to time in Alabama, Texas, Pennsylvania, New York, and California, as well as in many other states in smaller quantities. Low-grade amorphous graphite and graphitic shales have been mined in small quantities for foundry facings and paint in Rhode Island, Michigan, Nevada, Georgia, and other states. A small amount of lump graphite has been mined near Dillon, Mont.

Other countries which have appreciable graphite production, although generally of the lower grades, are Canada,¹⁶ India, Italy, Norway, Australia, China, South-west Africa, Spain, and Sweden.

Production and Consumption. There have been too few graphite producers in the United States in recent years to reveal even totals by states. Tables 2 to 4, showing total United States production, imports, and world production, are the only statistics published by the Bureau of Mines.

TABLE 2. PRODUCTION AND SHIPMENTS OF NATURAL GRAPHITE IN THE UNITED STATES, 1944 TO 1948

Year	Production, short tons	Shipments	
		Short tons	Value
1944	5,408	5,768	\$349,663
1945	4,888	5,334	289,207
1946	5,575	4,844	252,596
1947	4,387	5,207	221,260
1948	9,949	9,871	450,759

Manufactured or artificial graphite cannot be produced of crucible flake grade, but it does compete with natural graphite for lubricants, foundry mold wash, pencils and crayons, paints, polishes, and numerous minor uses. Several plants in this country and Canada produce artificial graphite, but production figures are not published.

Mining and Milling. In Alabama and Texas the graphite occurs in outcropping beds of schists and is mined by open-quarry methods. The crude ore is crushed in jaw crushers, rolls, and cone crushers, wet-ground in ball and rod mills,

GRAPHITE

and concentrated by oil flotation and tabling. The finished products are dried in rotary driers and sized by screening.^{5,11} Regrinding, if needed, may be done in buhr or hammer mills. Fine grinding of amorphous graphite and graphitic shales is usually done dry in Hardinge conical mills with air separators or in emery mills.

TABLE 3. GRAPHITE (NATURAL AND ARTIFICIAL) IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1942 TO 1946

Year	Crystalline				Amorphous				Total	
	Flake		Lump, chip, or dust		Natural		Artificial			
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1942	6,031	\$412,919	4,152	\$601,150	33,569	\$1,480,079	169	\$ 4,739	43,921	\$2,498,887
1943	5,311	493,382	1,012	117,795	22,390	331,800	205	15,515	28,918	958,492
1944	6,191	663,231	1,568	251,832	18,294	345,612	131	10,299	26,184	1,270,974
1945										
Brazil.....					33	\$ 3,638	...	...	33	\$ 3,638
Canada.....	101	\$ 25,120			1,178	92,308	154	\$ 6,223	1,433	123,651
Ceylon.....			1,324	\$187,771	842	118,020	...	...	2,166	305,791
Madagascar....	2,782	261,412	3,883	370,471	...	...	...	...	6,665	631,883
Mexico.....					25,879	350,063	...	...	25,879	350,063
Mozambique....					110	5,571	...	...	110	5,571
	2,883	\$286,532	5,207	\$558,242	28,042	\$ 569,600	154	\$ 6,223	36,286	\$1,420,597
1946										
Brazil.....					1	\$ 75	...	...	1	\$ 75
Canada.....	113	\$ 24,524			1,413	117,276	4	\$ 558	1,530	142,358
Ceylon.....			56	\$ 7,990	3,674	482,899	...	...	3,730	490,889
Cuba.....					1	50	...	...	1	50
France.....	24	5,133			...	...	...	...	24	5,133
India and dependencies...					168	18,086	...	...	168	18,086
Madagascar....	3,200	223,506			...	...	...	...	3,200	223,506
Mexico.....					24,389	441,189	...	...	24,389	441,189
Mozambique....					96	5,980	...	...	96	5,980
Switzerland....					1	280	...	...	1	280
	3,337	\$253,163	56	\$ 7,900	29,743	\$1,065,835	4	\$ 558	33,140	\$1,327,546

Grades and Specifications. The value of graphite, aside from competitive conditions, depends upon the type of material (lump, flake, amorphous, or artificial), its grade (content of graphitic carbon), and the size of grain. As noted before the most important types commercially are lump and flake suitable for making crucibles. The lower grades of lump and flake are largely by-products made in the preparation of crucible graphite. Lump graphite is represented mainly by Ceylon material, and the flake by the products from Madagascar, Canada, and the United States.

Ceylon graphite is divided into four main grades: ordinary lump (about 90 to 98 per cent graphitic carbon), chip (about 85 to 90 per cent graphitic carbon), dust

(about 55 to 85 per cent graphitic carbon), and flying dust (55 to 90 per cent graphitic carbon). Each of these grades may be further subdivided into best, medium, and poor classes. Usually, however, the following more simple classification is used; Nos. 1 and 2 lump, Nos. 1 and 2 chip and dust. Prices within the grades are based on quality.

TABLE 4. WORLD PRODUCTION OF NATURAL GRAPHITE, 1938 TO 1946, BY COUNTRIES, METRIC TONS^a
(Compiled by B. B. Mitchell)

Country ^a	1938	1939	1940	1941	1942	1943	1944	1945	1946
Argentina.....	28	.....	100	135	244	237	455	b	b
Australia:									
New South Wales.....	.....	.....	41	64	3	114	142	51	b
Queensland.....	10	.....	63	320	225	360	52	58	b
South Australia.....	.....	.....	.....	50	71	88	253	5	b
Tasmania.....	.....	.....	5	5	.....	7	.....	.....	b
Western Australia.....	.....	.....	1	c	6	11	.....	.....	b
Austria.....	16,852	24,013	22,991	24,264	26,203	31,305	24,617	3,483	b
Brazil (exports).....	.....	.....	.....	60	72	19	199	131	92
Bulgaria.....	.....	23	50	b	b	b	b	b	b
Canada.....	1,044 ^d	1,199 ^d	1,381 ^d	905 ^d	463 ^d	1,726	1,435	1,733	1,792
China.....	1,400 ^e	2,000 ^e	17,400	16,900	16,800	b	b	b	b
Ceylon (exports).....	11,972	22,756	24,414	27,670	27,872	20,820	12,461	7,946	2,356
Czechoslovakia.....	5,919	7,669	10,725	8,694	13,126	21,252	21,459	b	b
Egypt.....	.....	.....	.....	.....	.....	.....	260	152	.....
Germany, Bavaria.....	28,106	28,180	29,891	29,771	33,316	34,960	36,357	b	b
India.....	465	951	311	827	1,072	1,152	943	1,312	b
Indochina.....	.....	.....	.....	2	14	25	30	b	b
Italy.....	5,485	5,715	4,996	4,136	5,483	b	b	1,793	b
Japan.....	1,399	1,530	2,088	3,393	2,866	7,791	10,382	12,449	11,339
Korea (Chosen) ^d	57,318	83,415	94,273	68,640	96,054	96,471	103,306	b	b
Madagascar.....	14,545	12,196	15,311	13,018	9,562	12,949	14,478	9,185	8,875 ^d
Mexico.....	9,611	9,815	12,327	16,928	20,811	20,677	12,977	23,634	21,949
Morocco:									
French.....	307	886	529	571	1,067	265	213	262	637
Spanish.....	73	b	352	414	888	226	42	100	b
Norway.....	3,802	4,333	2,646	3,588	2,933	3,178	3,784	b	b
Portuguese East Africa.....	b	b	b	b	165	428	b	b	b
South-West Africa.....	.....	.....	71	188	181	1,758	1,973	1,477	762
Spain.....	.....	54	353	23	251	136	1,050	2,528	b
Sweden.....	192	549	153	205	174	171	.....	802	b
Union of South Africa.....	54	59	78	74	335	55	130	128	180
United States:									
Amorphous.....	f	f	f	} 2,493	6,459	9,016	4,906	4,434	5,058
Crystalline.....	f	f	.....					
Total ^a	159,000	205,000	241,400	223,000	267,000	286,000	271,000	208,000	b

^a In addition to countries listed graphite is produced in France, Greenland, Kenya, Nyasaland, and U.S.S.R., but production data are not available.

^b Data not available; estimate included in total except for 1946.

^c Less than 1 ton.

^d Exports.

^e Data represent areas designated as Free China during the period of Japanese occupation.

f Bureau of Mines not at liberty to publish figures.

High-grade flake graphite for making large crucibles should all be retained on a 50-mesh screen with as large a proportion as possible in coarse flakes (at least 8

per cent on 20 mesh); it should contain 85 to 90 per cent graphitic carbon; the flakes should be tough in order to resist breakdown during mixing; it should have a low packed volume to reduce clay binder to a minimum; and its oxidation rate should be low. Flakes of somewhat smaller size may be used in the smaller crucibles (up to 25 lb) and up to 10 per cent in foundry-size crucibles. Gwinn states, "The disadvantages of domestic graphite for use in the larger crucibles are (1) the preponderance of small-sized flakes, (2) low resistance to breakdown in mixing, (3) lack of uniformity in flake size and carbon content from shipment to shipment, and (4) larger packed volume."⁸ The suitability of graphite for crucible use depends upon a high density (high specific gravity), low surface factor (solid grain rather than thin flake), low ash, and high fusion point of the ash. Some of these points are in dispute, and the real value of a graphite for crucibles can only be determined by the actual manufacture and use of crucibles.

High-grade Mexican amorphous graphite contains about 86 per cent graphitic carbon. Low-grade domestic amorphous graphites used in paints, foundry facings, and so on, may contain as low as 35 to 50 per cent graphitic carbon.

No simple tests are used by which the quality of graphite or its suitability for various uses may be determined. The graphitic carbon content can only be determined by analysis.

Prices. In 1950 graphite was quoted per pound fob New York as follows: Ceylon lump, 10 to 14 cents; carbon lump, 10 to 11 cents; chip, 8 to 9 cents; dust, 4 to 6 cents; Madagascar flake, 12 to 15 cents; crude amorphous graphite from Mexico, screened through 1 in., minimum 80 per cent graphitic carbon, maximum 4 per cent moisture, \$56 per ton fob New York.

Utilization. The most recent compilation of the consumption of graphite in the United States by uses, quoted by Tyler in the Bureau of Mines "Minerals Yearbook," 1940 (review of 1939), brings our statistics up to only 1938, but the trends are probably still much the same today (see Table 5).

Crucibles composed of graphite bonded with clay are used in the manufacture of crucible steel and in melting brass and other nonferrous alloys. Steel crucibles are composed of approximately 50 per cent graphite, 30 per cent bond clay, 10 per cent sand, and 10 per cent kaolin; brass crucibles of 45 per cent graphite, 35 per cent bond clay, 10 per cent grog (burned fire clay or crushed, burned-clay products), and 10 per cent kaolin.

Foundry facings are finely pulverized materials used in foundries to give the surface of molds a smooth finish, so that castings may be removed freely and cleanly on cooling. Graphite is used more extensively than any other material for this purpose. Amorphous graphite or Ceylon dust is preferred, but flake-graphite dust is also used. The graphite is finely pulverized and is usually mixed with talc, soapstone, or other materials in varying proportions. A high degree of purity is not required.

Lubricants. Graphite of all types, in a finely pulverized form, is used extensively in the manufacture of various forms of lubricants. For this use the graphite must be entirely free from siliceous or other abrasive impurities. It may be used alone or mixed with greases, oil, or water. "Oildag" is a suspension of colloidal graphite in oil, and "aquadag" is a similar colloidal suspension in water,

both being made from artificial graphite. This process consists of deflocculating finely pulverized graphite by prolonged mastication in a water solution of tannin (3 to 6 per cent tannin by weight of graphite).*

TABLE 5. CONSUMPTION OF NATURAL GRAPHITE IN THE UNITED STATES FOR VARIOUS YEARS, BY KINDS AND BY USES

	Total consumption, short tons						
	1919 ^a	1919 ^b	1923 ^b	1924 ^b	1933 ^c	1937 ^d	1938 ^d
Amorphous graphite.....	6,500	12,500	29,500	26,500	5,813	21,000	12,100
Crystalline graphite.....	21,500	25,000	10,000	6,000	5,716	6,700	5,700
Total.....	28,000	37,500	32,500	32,500	11,529	27,700	17,800
	Per cent of total consumption						
Used for:							
Crucibles.....	55	45	15.0	13.0	17.5	8.3	10.3
Foundry facings, etc.....	10	25	43.5	51.5	38.0	38.5	28.4
Lubricants, etc.....	5	10	3.0	2.5	11.0	10.9	11.9
Pencils, crayons.....	10	5	9.0	5.0	12.0	10.6	9.7
Paint, stove polish, etc.....	15	10	18.5	19.5	12.0	4.0	3.3
Commutator brushes.....	...	...	8.5	5.0	3.5	0.6	0.8
Unspecified.....	5	5	2.5	3.5	6.0	27.1	35.9
	100	100	100.0	100.0	100.0	100.0	100.0

^a Estimated by Geological Survey.

^b Compiled by U.S. Tariff Commission; includes some artificial graphite.

^c Compiled by National Recovery Administration.

^d Compiled from reports of consumers and dealers to the Bureau of Mines.

Oilless bearings are made by impregnating wood, copper, bronze, or babbitt bearings with a special lubricating mixture containing graphite.

Pencils. The "lead" in "lead" pencils consists of a mixture of graphite, bond clay, and other materials, molded and baked for several hours at a temperature of 1500 to 2000°F. The hardness of the lead depends upon the relative proportions of clay and graphite. The following mixture has been used: graphite, 30 parts; clay, 9 parts; stibnite (antimony sulfide), 9 parts; tallow, 1 part. The graphite must be free from impurities and finely ground. In the United States, Bohemian graphite was formerly largely used, but now this has been superseded by Mexican amorphous graphite. A small amount of Ceylon graphite is used for pencils for special purposes. While the manufacture of pencils is an important industry in the United States, it probably does not consume over 1,000 tons of graphite per year.

Paint. Considerable graphite, usually of low grade, is used in the manufacture of graphite paints. Such paints are of chief value for the protection of metal surfaces, such as smokestacks, roofs, bridges, tanks, pipes, and so on, from the

* See E. G. Acheson, U.S. Patent No. 1345306, June 29, 1920, entitled "Method of Deflocculating Solid Substances."

corroding action of smoke, sulfurous gases, acids, and alkalies. It is usually mixed with silica or other inert filler; or low-grade, siliceous graphite mill tailings may be used.

Boiler Graphite. Very finely ground flake graphite (artificial and amorphous sometimes used) is used in boilers to prevent the formation of boiler scale or to break it up after it has formed. Its action is purely mechanical and it is said to be very efficacious.

Other Uses. There are a great variety of other uses for graphite, of which some of the more important are in the manufacture of graphite electrodes, brushes for dynamos and motors, dusting agents for electrotyping, fillers for dry batteries, stove polish, glaze and polish for powder and shot, various forms of steam packing, pipe cement, fertilizer filler, and for many other minor uses. Substantial tonnages of graphite have been employed in the atomic pile as a moderator, or as a slowing down agent for neutrons. Highly purified graphite is required, and the presence of minute quantities of impurities is objectionable.

Graphite electrodes and refractory shapes are not made from natural graphite. Petroleum coke, anthracite coal, and other forms of carbon are bonded with a pitch binder into either the finished form or a form from which the finished product will later be cut. These shapes are then graphitized in an electric furnace.⁹

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GYPSUM

Composition. Gypsum is hydrated calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O} : \text{CaO}$, 32.5 per cent; SO_3 , 46.6 per cent; H_2O , 20.9 per cent. Table 1 shows the range in composition of gypsum from several commercial deposits.

General Description. Gypsum is a common, soft mineral, white when pure, occurring over wide areas in the United States and in other parts of the world. Its chief commercial value depends upon its ability, after calcination, to set into a hard permanent cement or plaster (plaster of paris). It occurs in five varieties: (1) selenite, a transparent, cleavable form, usually colorless; (2) satin spar, a fibrous form with a silky luster; (3) alabaster, a massive fine-grained variety, usually white and translucent; (4) rock gypsum, a compact, granular form, coarser grained than alabaster, and often impure; (5) gypsite, an earthy, soft, impure form, noncoherent to slightly consolidated.

Physical Properties. *Hardness*, 1.5 to 2.5. *Specific gravity*, 2.3. *Melting point*, does not melt. Above 400°F it loses its water and forms CaSO_4 . *Index of refraction*, 1.520 to 1.529. *Color*, white or colorless when pure, but impure varieties gray to black, light pink to red and brown, pale yellow, pale blue. *Streak*, white. *Luster*, vitreous to pearly or silky, also earthy or dull. *Cleavage*, in selenite, perfect in one plane; fibrous, second direction at angles of 114° and 66° ; in massive varieties, uneven fracture. *Transparency*, selenite transparent, alabaster translucent, other varieties opaque. *Tenacity*, brittle. *Solubility*, soluble in hydrochloric acid, and slightly soluble in water (sufficient to give sulfate test with barium chloride).

Occurrence. Rock gypsum, of which most commercial deposits consist, usually occurs interbedded with sedimentary rocks. Gypsite or earthy gypsum occurs as surface beds, which are formed by the evaporation of gypsiferous water

TABLE I. ANALYSES OF GYPSUM

	Calcium oxide (CaO)	Sulfur trioxide (SO ₃)	Calcium sulfate (CaSO ₄) calcu- lated from SO ₂	Water, organic, loss on ignition, etc. (H ₂ O)	Iron and alumi- num oxides (Fe ₂ O ₃) (Al ₂ O ₃)	Silica and in- soluble residue (SiO ₂ , etc.)	Mag- nesium oxide (MgO)	Mag- nesium carbon- ate (MgCO ₃)	Calcium carbon- ate (CaCO ₃)	Carbonic anhy- dride, etc. (CO ₂ , etc.)	Sodium chloride, chlorine and potassium oxide (NaCl, Cl, K ₂ O)
California, Amboy ^a	32.7	44.7	75.99	19.7	0.2	....	....	....	....	....	0.13
Iowa, Fort Dodge ^b	31.18	44.51	75.67	20.05	0.74	1.30	....	....	2.37	....
Kansas, Blue Rapids ^b	33.51	46.65	79.31	18.84	0.17	0.65	0.19	....	....	....
Michigan, Grand Rapids ^c	32.94	44.70	75.99	19.00	1.83	1.28		....	....	11.02	
New Mexico, White Sands ^d	30.8	44.2	74.14	20.8	0.4	2.7	8.29	....	....
New York, Garbutt ^e	26.27	33.83	57.51	14.87	3.02	2.93		....	....
Oklahoma, Southard ^f	32.27	45.30	77.01	20.07	0.21	0.24		....	....
Utah, Nephi ^g	32.20	45.80	77.86	20.85	....	1.08	....	4.36			
Virginia, Plasterco ^h	31.51	46.72	79.42	15.60	Trace	0.75	....			

^a George Steiger, analyst. *U.S. Geol. Survey, Bull.* 413, 1910, pp. 27-30.^b U.S. Gypsum Co.^c *Geol. Survey, Mich.*, Vol. 9, pt. 2, p. 150, 1904.^d W. J. Gies, analyst. *Carnegie Inst. Wash. Pub.* 99, 1908, p. 16.^e G. E. Willcomb, analyst. *N.Y. State Museum, Bull.* 143, 1910, p. 60.^f *Geol. Survey, Okla.*, A. C. Sheard, analyst.^g Analyses furnished by producers.

and which are usually of limited thickness and extent. Satin spar and selenite usually occur in veins formed by crystallization from solution. Dunes of gypsum sand occur, formed by the piling up of gypsum grains eroded from other gypsum deposits and transported by the wind.

Bedded deposits of rock gypsum of principal commercial importance are those deposited from solution by the evaporation of sea water. Since sea water contains only 3.5 per cent of mineral salts in solution, of which the calcium sulfate content is only 3.6 per cent, the great thickness of some gypsum beds can hardly be accounted for by direct, simple evaporation. It is probable that such beds were formed in isolated basins with no direct inflow from the sea, but fed with highly concentrated waters from other basins as fast as their own waters evaporated. Other bedded deposits of gypsum were doubtless formed from beds of limestone by alteration by solutions carrying sulfuric acid.

Geographically, gypsum is very widely distributed and it has been used for thousands of years. The Assyrians used alabaster for carving and the Egyptians used calcined gypsum plaster in building the pyramids. The large gypsum-producing countries today, in approximately the order of their present production, are the United States, Great Britain, Canada, and France.

United States. Gypsum is mined or quarried in 17 states as shown in Table 2. For many years New York has been the leading producer, until surpassed recently by Michigan. Gypsum interbedded with shales and limestone extends in a belt over 150 miles long by 10 to 20 miles wide through the central part of the state, starting east of Syracuse and extending nearly to Buffalo. Most production is now obtained by underground mining. Quarries were operated in the eastern end of the belt where exposures were available in the early development of the industry. The move to underground mining in the western area was due in part to the greater purity of the mineral. The establishment of gypsum-manufacturing plants in New York harbor, employing imported rock from Canada, eliminated much of the upstate production from the Metropolitan area. The widespread nature of gypsum occurrences is indicated by the list of producers. This does not represent all potential producers, since the abundance of the material is such that other states could qualify if economic conditions justified development. Many new operations could be initiated in the present producing states if a market existed for the product. In common with other large tonnage nonmetals the market is more important than the deposit of raw material. The increase in population on the west coast and the accompanying expansion in building have been reflected in an increased demand for gypsum products, which has stimulated production in California and Nevada. Reserve tonnage for future use is adequate for a long period.

Canada. Many large deposits of gypsum occur in Canada, but those most extensively worked are in the Maritime Provinces of Nova Scotia and New Brunswick. Much of this material is of exceptionally high grade. A proportion of the Nova Scotia gypsum, relatively small, is calcined in Canada, but much of it exported by boat to the United States, where it is calcined in plants extending from New Hampshire to Florida.

The principal deposits in *Nova Scotia* are in the following districts: Hants

TABLE 2. CRUDE GYPSUM MINED IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944			1945			1946		
	Active mines	Short tons	Value	Active mines	Short tons	Value	Active mines	Short tons	Value
Arizona.....	1	107,179	\$ 133,306	1	120,422	\$ 160,156	2	212,231	\$ 456,361
Arkansas.....	2	502,629	799,882	2	455,319	967,507	1	574,345	1,315,699
Kansas.....	6	137,773	254,894	5	129,587	243,214	6	199,895	474,704
California.....	2	398,143	655,392	3	430,843	569,964	3	560,094	1,172,500
Colorado.....	2	552,672	891,965	2	640,186	862,028	2	1,120,070	2,171,979
Montana.....	1	392,748	693,107	1	368,246	732,253	1	490,253	1,164,083
South Dakota.....	1	594,067	1,128,821	1	557,902	1,262,989	2	814,999	1,961,157
Wyoming.....	5	515,075	1,023,140	5	477,595	1,356,592	2	584,755	1,482,269
Iowa.....	4	216,012	380,622	2	223,983	317,752	2	301,123	612,148
Michigan.....	3	344,936	489,638	2	407,640	511,869	2	771,633	1,630,929
Nevada.....	7	3,761,234	\$6,450,767	6	3,811,723	\$6,984,324	6	5,629,398	\$12,441,829
New York.....	2			49			52		
Ohio.....	2								
Virginia.....	2								
Oklahoma.....	2								
Utah.....	2								
Texas.....	7								
	49								

County, near Windsor; Cumberland County, near Amherst; Victoria County, near McKinnon Harbour; Baddeck and St. Ann; Inverness County, near Cheticamp; Guysborough and Antigonish; Picton, Halifax, and Colchester; along the coast of Cape Breton Island, in the interior and along the shores of the Bras d'Or lakes. The beds in many cases attain a thickness of 100 ft.

Gypsum deposits in *New Brunswick* are not so numerous as in Nova Scotia, but are important. The following are the principal districts: Albert County, near Hillsborough; Westmoreland County, near Petitcodiac; in Kings County; Victoria County, at Plaster Rock on the Tobique River.

In *Ontario*, only two general districts are known. The southern district is in the vicinity of the Grand River from 1 mile above Paris in Brant County to a few miles below Cayuga in Haldimand County. These beds vary in thickness from 4 to 11 ft and are the only deposits now worked in the province. The northern district is on the banks of the Moose River 30 to 40 miles south of Moose Factory on James Bay. These deposits are too remote from a railroad to be of present importance.

Gypsum occurs in several localities in *Manitoba*, but the one principally developed is in the northern part of the province, 10 to 12 miles northwest of Lake St. Martin and about 170 miles north of Winnipeg. These deposits are stated to cover 8 square miles. A deposit of pure-white gypsum was located by drilling at a depth of 325 ft about 18 miles east of Dominion on the Canadian Pacific Railway. Deposits are known to occur in other provinces.

Foreign Countries. Egypt, India, Italy, Japan, Russia, and the Union of South Africa are large producers and consumers. Production in varying amounts is recorded in many other countries.

Mining. Gypsum occurs in such a variety of ways under such varying conditions and it is produced in so many different localities by operations varying so greatly in size and character that it is beyond the scope of this work to give an adequate exposition of the subject.

Most of the gypsum produced in the United States is rock gypsum, occurring in beds of varying thickness. There is relatively small production of gypsite, which occurs as a soft earthy material or loose sand in bed or dunes with little or no overburden.

The rock-gypsum beds which have been worked in the past have usually cropped out at the surface, but a few beds are being worked which do not crop out and which were discovered by drilling. In opening a new deposit it is customary to strip back the overburden and work it as an open quarry until the overburden becomes too heavy for economical operation. The bed is then opened by adit tunnels or by shafts, and the rock is removed by underground mining operations. Stripping may be done by hand, by drag-wheel or dragline scrapers, by steam shovel or by hydraulicking, depending upon the nature and the thickness of the overburden, the size of the operation, the inclination of the bed, and so on. The beds of gypsum worked vary from a few feet to 15 or 20 ft in thickness. After the stripping is removed, the rock is drilled, shot down by explosives, and loaded by hand or by steam shovel into cars, wagons, trucks, or tramway buckets, in which it is transported to the mill. If hand loading is used, there is an opportunity to sort out waste.

In many places quarries have been very unsystematically developed. When the overburden became too heavy in one place, operations there were abandoned and a new opening started at another point on the outcrop. Sometimes, however, the overburden is light over a large area, and large-scale systematic development has resulted.

When the overburden becomes excessive, where it is of rock rather than loose dirt, where the bed is tilted at a high angle, or where the bed is discovered at a considerable depth by drilling and does not crop out, underground mining methods must be adopted. Gypsum has such a low relative value and occurs in such abundance, often in horizontal or nearly horizontal beds, that the problems of mining are closely analogous to those in mining bituminous coal. Expensive, complicated methods cannot be used and a high recovery must often be sacrificed to low production costs. Gypsum-mining methods therefore often resemble coal-mining methods.

The mine may be opened by tunnels from the outcrop or by inclined or vertical shafts. If the bed is horizontal or nearly so, long entries are driven, from each side of which, after leaving proper pillars to protect the entries, mining is started. The most common method is the ordinary room-and-pillar system. If the beds contain impurities and these are segregated, it is sometimes possible to leave them standing as pillars. If the roof is good, the whole thickness of the bed may be mined out, but if it is weak, a layer of gypsum may be left to protect it. Sometimes the bed is split by a "parting" of limestone or shale, which must be sorted out after blasting. If the bed stands at a high angle, some form of stopping must be used. Very little timber is used in gypsum mining.

If the pillars left are of good gypsum, the extraction on first mining may vary from 60 to 75 per cent. If there is no necessity for preserving the surface, the pillars may be removed by a second mining and the roof allowed to cave. The development of gypsum mines has often been very irregular and unsystematic.

Drilling is usually done by hand, compressed-air or electric augers, or by compressed-air drills. Few holes are necessary and low-grade explosives (either black powder or low-grade dynamite) are used, for gypsum breaks easily. The broken ore is loaded into cars usually holding from 2 to 5 tons each and is trammed by hand, by mule, or by motor to the main haulage way. Here trains are made up and hauled to the surface or to the shaft by mules, cables, or motors.

In mining gypsum, care must be taken that the grade is maintained. Impurities must be avoided or sorted out, and low-grade rock (suitable for agricultural gypsum) must be kept separate from high-grade rock (for plaster). Moreover, beds of gypsum sometimes abruptly change to anhydrite (anhydrous calcium sulfate), which is valueless for the manufacture of plaster.

Some anhydrite can be disposed of mixed with gypsum as a retarder in the manufacture of portland cement. It is preferred to gypsum for agricultural use, being nearly pure calcium sulfate, not diluted by water of crystallization as is the case with gypsum.

Gypsite deposits have little or no overburden, and are often so small that extensive operations are not justified. Sometimes the gypsite is soft enough to shovel directly into wagons or cars. In other cases it is excavated by horse

scrapers either with or without preliminary loosening by disk harrows. Steam shovels may also be used, but are not common at the small deposits usually worked.

Milling. With the exception of Atlantic and Pacific ports, supplied by imports, mills are located near the mine or quarry. The mills are designed to crush the rock to desired size. The crushed gypsum is directed toward two major markets. It may be sold without change, except for screening or grinding, or it may be converted to a new compound possessing cementitious properties by calcining. Crushed gypsum, generally between $\frac{1}{2}$ and 2 in. in size, is sold to the manufacturers of portland cement for retarder. It may be ground to a fine powder for application to the soil. Mixed cargoes of gypsum and anhydrite are delivered to Norfolk, Va., for grinding and use in agriculture. Terra alba is finely ground gypsum selected to provide a bright white product.

Calcination. When gypsum is heated it rises steadily in temperature until it reaches 128°C , or 262°F . At this point there is a halt in the rise of temperature accompanied by absorption of heat, indicating a chemical reaction. This is the elimination of water. At this point gypsum starts to decompose with a release of a portion of its water of crystallization. The hemihydrate, $2\text{CaSO}_4 \cdot \text{H}_2\text{O}$, begins to form. This reaction is the basis of the plaster industry, since the hemihydrate possesses hydraulic properties, that is, it can react with water and return to its original form of gypsum, $2\text{CaSO}_4 \cdot \text{H}_2\text{O} + \text{H}_2\text{O} = 2[\text{CaSO}_4 \cdot \text{H}_2\text{O}]$. However, the gypsum now formed is in needlelike monoclinic crystals. These interlace and form a strong well-knit mass. This reaction is characteristic of "plaster of paris," so-called due to the development of the plaster business in the Paris basin. Upon continued heating the temperature rises again to 163°C , or 325°F . At this point the hemihydrate starts to lose water, eventually forming CaSO_4 , called soluble anhydrite. This form of calcium sulfate is very unstable and upon exposure to the air promptly assimilates enough water to revert to gypsum, $\text{CaSO}_4 \cdot \text{H}_2\text{O}$. Upon continued heating to red heat a stable CaSO_4 , similar to the mineral anhydrite, is formed. The manufacture of plaster consists of a control of temperature and time, regulated to produce a product of desired performance.

Calcination in the United States and Canada is usually done in a special type of apparatus known as a "gypsum kettle."

The gypsum calcining kettle is a hollow vertical cylinder made of boiler plate, having a convex iron or steel bottom, resting on a masonry firebox, and surrounded by a brick shell. Kettles have a diameter of 8 to 14 ft, a depth of 6 to 10 ft, and a capacity of 7 to 20 tons of ground gypsum per charge. They are heated by a coal, oil, or wood fire applied in a firebox beneath the kettles. The heat also passes around the sides of the kettle and through two to four flues, about 14 in. in diameter, which pass horizontally through the kettle. The top is covered by a lid, with charging doors, through the center of which passes a vertical, gear-driven shaft carrying at its bottom a crossarm with stirring paddles. The stirrer is run at about 15 to 20 rpm and usually requires about 15 to 20 hp. A typical kettle is illustrated in Fig. 9.

The ground gypsum is fed in through the charging doors with the kettle heated to 212°F . The temperature is gradually raised, and at 248°F the charge begins to

boil. The temperature is brought to a maximum, generally between 340 and 350°F. The time of calcination varies from 1 hr (for first-settle stucco) to as much as 3 to 5 hr, but averages under 2 hr. After calcination the material is discharged through a gate into a fireproof cooling bin to a floor.

After the kettle-calcined gypsum has cooled, it must be screened to remove coarse lumps, which are reground. The screening may be done by various types

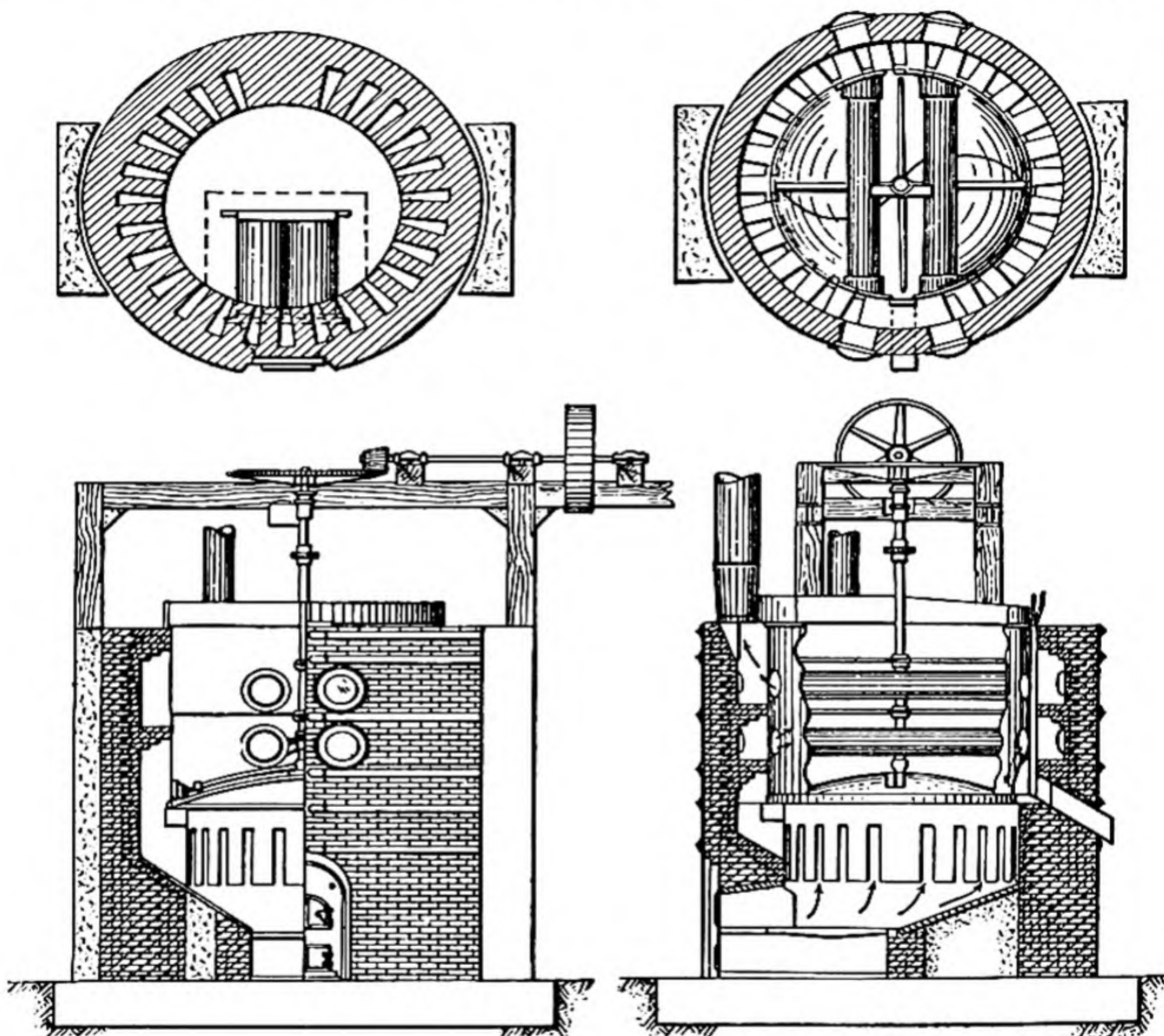


FIG. 9. Gypsum calcining kettle.

of rotary, impact, or vibrating screens, but inclined impact screens of the Newago type are perhaps the most common.

The kettle is used for all types of plaster. It is useful where special products of high quality are desired, due to the control of conditions which can be maintained during operation.

The rotary kiln is used in many mills. The type of kiln employed is similar to those used in the portland cement and lime industries. Shorter kilns are used, generally around 150 ft maximum in length. Rock gypsum, screened to desired

size, about 1 to $\frac{1}{2}$ in., is fed to the kiln. The temperature and rate of travel must be operated in such a manner as to permit the calcination of the gypsum without overburning or discharge of cores of raw material. The discharge is ground fine in tube mills. The temperature attained by friction and impact in the tube mill is sufficient to calcine any unburned rock. The rotary kiln has the advantage of continuous operation, high output, and low costs of operation. It requires a considerable investment and produces a less uniform product compared to the kettle; therefore, it is used for plaster for construction use and not for special products.

The calcined product at this stage is known as stucco or plaster of paris and has an ideal composition of $2\text{CaSO}_4 \cdot \text{H}_2\text{O}$ (about 93.8 per cent CaSO_4 and 6.2 per cent H_2O). When pure and ground to 80 to 90 per cent through 100 mesh, it starts to set in 6 to 10 min, but when impure it may take an hour. In order to control the rate of setting, accelerators or retarders must be thoroughly mixed with the plaster. The action of accelerators and retarders seems to be mechanical in that they hinder or help the crystallization of the gypsum. Retarders are usually dispersing or deflocculating agents, and accelerators are coagulating or settling agents.

As retarders, organic materials such as glue, glycerin, flour, blood, and sugar are commonly used. The most common retarder used in the United States is made from hoof meal or low grades of hair, to which is added caustic soda to reduce it to glue and lime to dry the glue solution. From 2 to 15 lb of retarder per ton of plaster is commonly used. Practically all gypsum wall plaster is retarded so that when mixed with 2 parts of sand by weight it will show an initial set in about $2\frac{1}{2}$ hr. By the addition of potassium sulfate, alum, or common salt the set may be accelerated to a matter of a few minutes. Nothing has contributed more to the industrial success of gypsum plasters than the development of these controlling agents by which a uniform material of controlled setting time can be assured. Other materials may be added to stucco to improve performance. Fibers, hair, or wood fiber are frequently added to wall plaster to increase strength and hold the plaster in position until the final set has locked the material in permanent form.

Special plasters are prepared by unique calcining methods. Alpha gypsum¹⁰ is prepared by a totally different technique. Gypsum rock in 2-in. lumps is placed in a closed cylinder or autoclave to which steam pressure is applied. No agitation is required, and as the temperature rises the water of crystallization in the gypsum is eliminated, producing the equivalent of a hemihydrate. Calcination is completed at a temperature of around 250°F. The product, marketed as "Hydrocal,"⁹ possesses properties different from other plasters. The individual particles appear as short, broad, dense crystals. When mixed with water to produce a smooth-flowing plaster it is apparent that far less mixing water is needed than is required for ordinary plasters. The plaster when set is a remarkably strong and dense product. This material is particularly useful in dental laboratories and wherever a product of superior performance is useful (see also Ref. 2).

Lump gypsum may be calcined in small, vertical kilns, similar in principle to

those used for lime. The temperature is brought to a red heat, completely dehydrating the gypsum and producing an anhydrous calcium sulfate. This material alone possesses no hydraulic properties, but when finely ground and mixed with certain accelerators, borax, alum, or other sulfates, it will set slowly. This product is known as *Keene's cement*. It produces a hard plaster, capable of taking a polish and more resistant to water than common plasters. It is used to create hard walls with resistance to water attack. It may be colored, and patterns introduced by the inclusion of dyed threads that are removed before the plaster sets, leaving an intricate design which may be brought down to a highly polished surface. Panels and columns in the lobbies of public buildings are frequently made in this manner.

Utilization. Gypsum rock is rarely used as building stone due to its solubility in water. Although this is slight, long exposure shows damage. Alabaster, a dense, translucent variety of gypsum sometimes displaying an attractive pattern, has been employed for ornamental purposes for centuries. It has been produced in Italy, near Leghorn, for many years. A portion of this production is imported in the United States for manufacture into lamp bases, bowls, book ends, and similar objects. It is mined near Livermore, Colo. The extraction of the rock requires care to prevent shattering and the development of incipient fractures. Slow, black powder is employed as an explosive, and pieces of alabaster are loosened by channeling and with the use of wedges. The rock may be cut with an ordinary saw. Carborundum saws are used to cut off slabs. Blocks may be set up in a lathe and turned to desired form. Polishing is done with a series of graded abrasives used wet. The final polish is accomplished with a buffing wheel. Although alabaster is one of the softest of minerals it is useful and attractive for ornamental use where abrasion is not a factor.

The use of gypsum as a retarder in portland cement has been mentioned in the section dealing with that subject. This is the largest tonnage consumer of raw rock and in 1948, 1,674,944 tons were sold in this market. This is a low-priced commodity and is sold at prices between \$3 and \$4 per ton.

Agricultural gypsum, sometimes called land plaster, is the second largest consumer of raw rock, and in 1948 the amount sold in this market amounted to 516,899 tons. Anhydrite, with its higher calcium sulfate content, is frequently used. Calcium sulfate has been found to be particularly valuable in promoting the growth of legumes. The peanut belt of the Carolinas and Virginia is a large consumer. Part of this market is supplied by imports from Canada laid down at Norfolk, Va. Gypsum provides sulfur for such plants as alfalfa, beans, peas, vetch, and the peanut. The capacity of these plants to fix nitrogen is increased by their greater root growth. Calcium sulfate also promotes the assimilation of potash from the soil. Its action, therefore, is complex and valuable to the growth of many plants. It is used also to correct black alkali soils, for it reacts with the sodium carbonate present and changes it to harmless calcium carbonate and the less objectionable sodium sulfate.

Selected white rock is finely ground and sold as "terra alba." This is used as filler in the manufacture of paper, in paints, as a nutrient in the growing of yeasts,

TABLE 3. GYPSUM PRODUCTS (MADE FROM DOMESTIC, IMPORTED, AND BY-PRODUCT CRUDE GYPSUM) SOLD OR USED IN THE UNITED STATES, 1945 TO 1946, BY USES

Use	1945			1946				
	Short tons	Value		Short tons	Value		Per cent of change in	
		Total	Average		Total	Average	Ton-nage	Average value
Uncalcined:								
Portland-cement retarder.....	664,247	\$1,502,689	\$2.26	1,135,853	\$2,949,860	\$2.60	+71	+15
Agricultural gypsum.....	462,217	1,715,982	3.71	471,902	1,855,515	3.93	+2	+6
Other uses ^a	21,333	214,056	10.03	33,524	300,414	8.96	+57	-11
Total uncalcined uses.....	1,147,797	\$3,432,727	.....	1,641,279	\$5,105,789	.....	+43	
Industrial:								
Plate-glass and terra-cotta plasters...	20,317	\$136,378	6.71	36,654	\$284,716	7.77	+80	+16
Pottery plasters.....	30,807	414,187	13.44	44,808	627,913	14.01	+45	+4
Orthopedic and dental plasters.....	13,907	416,712	29.96	13,322	439,471	32.99	-4	+10
Other industrial uses ^b	92,765	1,359,086	14.65	112,394	1,808,888	16.09	+21	+10
Total industrial uses.....	157,796	\$2,326,363	.....	207,178	\$3,160,988	.....	+31	
Building:								
Cementitious:								
Plasters:								
Base-coat.....	640,276	\$6,103,402	9.53	1,507,115	\$16,088,863	10.68	+135	+12
Sanded.....	68,485	428,631	6.26	113,983	864,579	7.59	+66	+21
To mixing plants.....	10,938	70,827	6.48	15,553	121,857	7.83	+42	+21
Gaging and molding.....	88,800	1,084,902	12.22	165,061	2,230,931	13.52	+86	+11
Prepared finishes.....	6,663	213,211	32.00	11,753	445,864	37.94	+76	+19
Insulating and roof-deck.....	35,300	286,302	8.11	70,956	623,844	8.79	+101	+8
Other ^c	14,918	681,930	45.71	21,326	1,190,576	55.83	+43	+22
Keene's cement.....	14,158	217,723	15.38	32,476	482,717	14.86	+129	-3
Total cementitious.....	879,538	\$9,086,928	.....	1,938,223	\$22,049,231	.....	+120	
Prefabricated:								
Lath.....	445,497	\$8,177,308	13.64 ^d	865,682	\$18,550,334	16.17 ^d	+91 ^e	+19 ^d
Wallboard.....	1,023,537	28,994,151	22.53 ^d	1,517,035	43,699,483	22.99 ^d	+48 ^e	+2 ^d
Sheathing board.....	102,692	2,304,165	22.90 ^d	79,673	2,021,691	26.29 ^d	-24 ^e	+15 ^d
Laminated board.....	125,222	4,002,216	34.23 ^d	22,837	792,560	37.18 ^d	-82 ^e	+9 ^d
Tile.....	104,943	1,824,736	42.62 ^f	108,721	1,814,487	47.92 ^f	+5 ^e	+12 ^f
Total prefabricated.....	1,801,891	\$45,302,576	.....	2,593,948	\$66,878,555	.....	+44	
Total building uses.....		\$54,389,504	.....		\$88,927,786			
Grand total value.....		\$60,148,594	.....		\$97,194,563			

^a Includes uncalcined gypsum sold for use as filler and rock dust, in brewer's fixe, color manufacture, and for unspecified uses.

^b Includes statuary, industrial casting and molding plasters, dead-burned filler, granite polishing, and miscellaneous uses.

^c Includes joint filler, patching and painter's plaster, and unclassified building plasters.

^d Average value per thousand square feet.

^e Per cent change in square footage.

^f Average value per thousand square feet of partition tile only.

GYPSUM

and for a number of other unspecified purposes. Ordinary off-white gypsum is also ground and used as a carrier for insecticides and as a filler.

Raw gypsum finds other uses in small amounts. It is employed as a flux in some smelting operations and is calcined with ferrous sulfate in the manufacture of venetian red. It has been used in Europe as a source of sulfuric acid and cement. It is a potential reserve of sulfur of great size, which undoubtedly will become important commercially in the future.

TABLE 4. GYPSUM BOARD AND TILE SOLD OR USED IN THE UNITED STATES, 1944 TO 1948, BY TYPES

Year	Lath			Wallboard		
	M square feet	Value		M square feet	Value	
		Total	Average ^a		Total	Average ^a
1944	625,553	\$ 7,908,857	\$12.64	1,208,158	\$26,507,684	\$21.94
1945	599,431	8,177,308	13.64	1,286,912	28,994,151	22.53
1946	1,147,353	18,550,334	16.17	1,900,779	43,699,483	22.99
1947	1,703,818	32,241,998	18.92	2,046,216	53,122,413	25.96
1948	2,504,733	53,596,957	21.40	2,531,865 ^e	72,071,432 ^e	28.40

Year	Sheathing			Laminated board			Tile ^b		
	M square feet	Value		M square feet	Value		M square feet	Value	
		Total	Average ^a		Total	Average ^a		Total	Average ^c
1944	114,704	\$2,300,069	\$20.05	167,580 ^d	\$4,714,096	\$28.13	15,067	\$1,426,560	\$41.63
1945	100,627	2,304,165	22.90	116,908 ^d	4,002,216	34.23	17,988	1,824,736	42.62
1946	76,914	2,021,691	26.29	21,317 ^d	792,560	37.18	18,865	1,814,487	47.92
1947	106,482	3,534,686	33.20	1,741	202,683	116.42	26,769	2,775,676	67.37
1948	129,632	4,431,544	34.19	^e	^e	/	27,181	3,091,547	72.40

^a Per thousand square feet, fob producing plant.

^b Includes partition, roof, floor, soffit, shoe, and all other gypsum tiles and planks.

^c Per thousand square feet, fob producing plant, of partition tile only.

^d Reported as area of component board and not of finished product.

^e Laminated board included with plywood.

/ Bureau of Mines not at liberty to publish figures.

Calcined Gypsum. Ordinary mine-run gypsum is used for the large-tonnage markets. These include base coat, sanded and fibered, and the common grades used in construction and in the fabrication of lath, wallboard, sheathing, laminated board, and tile. Pure, white gypsum selected for color is used in special plasters designed for industrial purposes such as terra-cotta plaster, pottery plaster, molding plaster, orthopedic and dental plasters, statuary plaster, and

gaging plaster used with hydrated lime to make the finish coat for the wall of the average house. Lath and board of various types is manufactured in machines to specified length, breadth, and thickness. Board consists of a sandwich of plaster between sheets of heavy paper frequently made in mills owned by gypsum companies. As the plaster sets, the acicular crystals of gypsum penetrate the paper and produce a strong bond. These fabricated products are sawed and nailed easily and possess admirable fire resistance. They have been useful and in great demand in the postwar building boom. Tile exhibits similar desirable fire resistance.

The production of gypsum products is shown in Table 3 for recent years. The production of fabricated products is shown in Table 4.

Small amounts of gypsum have been made synthetically by the treatment of calcium carbonate with sulfuric acid. This was done during the war to produce plaster for orthopedic use when normal supplies were not obtainable in all European countries. Gypsum is produced as a by-product in the production of hydrofluoric acid from fluorspar and in the manufacture of baking powder. Some of this artificial gypsum is converted to plaster and competes with the natural mineral.

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IODINE

General Description. Iodine is an element with an atomic weight of 126.92, the heaviest nonmetallic element. Its vapor is one of the heaviest known gases and violet in color. It was named for the Greek word for violet shortly after its discovery in 1811.

Physical Properties. *Melting point*, 114.2°C. *Boiling point*, 184.3°C. *Specific gravity*, 4.933.

Occurrence. Iodine was recovered first from kelp, a variety of seaweed that contains from 0.1 to 0.3 per cent when dry. This material is still utilized to supply a small and irregular production. Substantial amounts in assured supply were not available until recovery methods were introduced in the nitrate industry of Chile. Iodine occurs in the caliche as calcium iodochromate or as iodates of calcium, sodium, or potassium. These compounds accumulate in the liquor from which the nitrates have been extracted to a concentration varying from 8 to 15 g per l. Iodine is also found in brines associated with oil wells in Louisiana and California. The exploitation of this source has made the United States independent of imports from foreign sources.

Production. The most ancient method, recovery from seaweed, as practiced in Japan, France, and other European countries, involves the collection of the weed from the shore. The weed is dried and then burned in a trench to confine the ash. The ash, first known as kelp, from which the weed derived its name, will produce from 12 to 35 lb of iodine per ton. The ash is leached with water and acidified with hydrochloric or sulfuric acid, and then manganese dioxide is added. This mixture is heated, resulting in the liberation of iodine, which is condensed in earthenware retorts. Further purification may be attained by sublimation or solution in a concentrated solution of potassium iodide, from which the iodine may be precipitated by the addition of an excess of water.

Iodine is recovered as a by-product of the nitrate industry in Chile. It is present in the caliche in an average content of about 0.06 per cent. It is extracted from the solution after the removal of the sodium nitrate by the addition of sodium bisulfite, or the additions of thiosulfate and sulfuric acid, or by passing sulfur dioxide gas through the liquor. The precipitated iodine is filtered and washed and then pressed into cakes. Purity is raised to approximately 99.5 per cent by sublimation. The iodine is placed in kegs, often wrapped in rawhide, and placed in storage awaiting export orders. Production capacity is in excess of world consumption, which has been estimated to be from 1,200 to 1,400 tons.

Iodine was sold for a price around \$4 a pound. It was suspected that the production costs were one-tenth or less of the selling price. This led to exploration in other countries, and production was increased in the United States and Russia from oil-well brines, and in Japan, Norway, and France from seaweed. The Chilean monopoly was thereby broken and prices declined. In 1950 resublimed iodine was quoted at \$2.30 per pound.

Iodine was extracted first from oil-well brines in Louisiana in 1928. Operations were transferred later to Los Angeles County, Calif., an area now believed capable of supplying the requirements of the United States. The oil-well brines are dilute solutions of iodides containing from 30 to 70 ppm of iodine. Different processes have been used for extraction. In the silver process the brine is clarified by filtration and a solution of silver nitrate is added. Silver iodide is precipitated, assisted by the addition of ferric chloride. The precipitated sludge is pumped out and the ferric chloride removed by the addition of hydrochloric acid. Steel scrap is then added, forming metallic silver and ferrous iodide. The silver is recovered and converted to silver nitrate. The ferrous iodide is oxidized with sodium dichromate and sulfuric acid. Granular iodine is precipitated. This is collected, melted under concentrated sulfuric acid, and tapped off for cooling in cakes. Material with purity of up to 99.8 per cent is obtained. In the carbon process, the clarified brine is acidified with sulfuric acid. Sodium nitrite is added and the iodide altered to iodine. The solution is treated with activated carbon, which is used until saturated. This is then filtered and treated with caustic soda, forming sodium iodide. This solution is now oxidized with sulfuric acid and dichromates. The iodine formed is collected, melted, and sublimed. The total production of iodine in the United States is now known. It is estimated to have approximated a half million pounds per year.

Imports of iodine are shown in Table 1, from the U.S. Bureau of Mines.

Utilization. Iodine is used in solution and in combinations, such as iodoform, as a medicinal antiseptic. It is also used as a preventive of goiter; for this purpose iodides are added in small amounts to table salt. The silver salts of iodine are sensitive to light and are used in photographic emulsions. A number of iodine reagents are used in the laboratory and in limited amounts in industry.

TABLE 1. CRUDE IODINE IMPORTED FOR CONSUMPTION IN THE UNITED STATES

Year	Pounds	Value
1943	2,744,930	\$3,041,609
1944	1,204,303	1,321,274
1945	220,526	232,070
1946	886,578	976,190
1947	2,260,506	2,756,888
1948	592,136	847,752

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JADE (NEPHRITE AND JADEITE)

Jade is a term given to two minerals, nephrite and jadeite, which closely resemble each other both in appearance and in physical properties and which are used for the same purposes. Therefore, they will be considered together.

Composition. *Nephrite*, the more common form, is a calcium-magnesium-iron silicate, having the formula $\text{Ca}(\text{MgFe})_3(\text{SiO}_3)_4$. *Jadeite* is a sodium aluminum silicate $[\text{Na}_2\text{Al}_2(\text{SiO}_3)_4]$. The accompanying table shows analyses of nephrite and jadeite.

General Description. Nephrite and jadeite are hard, exceedingly tough minerals usually found in boulders or large masses. They are often green, but also occur in a great range of other colors.

ANALYSES OF JADE

	1	2	3	4	5
SiO_2	58.88	59.18	56.73	56.12	56.39
Al_2O_3	25.93	22.96	3.22	0.63	1.63
Cr_2O_3	0.12				
Fe_2O_3	0.24	1.87	{ 1.88	.....	1.72
FeO			{ 2.51	7.45	3.70
MnO}.....	.....	.....	0.26	Trace	0.26
CaO	0.40	1.52	13.24	12.72	7.92
MgO	0.36	0.67	19.42	20.92	24.63
K_2O	0.63	Trace	Undet.	Undet. }	None
Na_2O	11.64	12.71	Undet.	Undet. }	
$\text{H}_2\text{O} -$	1.81	0.90	0.83	1.42	{ 0.65
$\text{H}_2\text{O} +$					{ 3.42
CO_2			Trace	.....	0.13
NiO, CaO}.....	.....	.....	
	100.01	99.81	99.40	99.26	100.45

1. *Jadeite*. Light-colored bead mottled with emerald green, from state of Oaxaca, Mexico. Specific gravity 3.007, determined by William Hallock; analyses by F. W. Clarke, U.S. Geol. Survey.

2. *Jadeite* (fragment from Sardinal, Costa Rica). Pale-green translucent. Specific gravity 3.32, Clarke. Analyses by Clarke.

3. *Nephrite* (New Zealand). Fragment from a dark-green boulder. Analyses by Clarke.

4. *Nephrite* (St. Michael, Alaska). Dull apple green, fairly uniform in tint, semi-translucent at edges. Specific gravity 3.006, Hallock. Analyses by Clarke.

5. *Nephrite* (Jordansmuhl, Silesia). Typical material from an old locality. Analyses by George Steiger, U.S. Geol. Survey.

Physical Properties. *Hardness*, nephrite, 5.5; jadeite, 6 to 7. *Specific gravity*, nephrite, 2.97 to 3.18; jadeite, 3.3 to 3.35. *Melting point*, nephrite fuses at 4 (possibly 1300 to 1350°C) to colored glass; jadeite fuses very easily (2.5) with yellow flame to transparent bubbly glass. *Index of refraction*, nephrite, 1.61; jadeite, 1.654. *Color*, very variable for both nephrite and jadeite. The commonest colors commercially are all shades of green, white and green, and white streaked and mottled. Other colors are yellow, orange, red, brown, gray, blue, pale lavender, and nearly black. *Streak*, white. *Luster*, greasy and oily when polished; dull on fracture. *Cleavage*, none when massive, faint in thin section. *Fracture*, uneven. *Transparency*, translucent to semitranslucent in light-colored varieties to opaque in dark varieties. *Tenacity*, very tough in both nephrite and jadeite, jadeite less tough when granular. Toughness in both nephrite and jadeite is due to an interlacing of fine crystals and fibers, which are usually of microscopic size but sometimes large enough to be seen with the unaided eye. Sometimes jadeite is granular instead of fibrous.

Occurrence and Production. Nephrite occurs in Turkestan in the valleys of the Karakash, Yarkand, and Kashgar rivers, in masses 20 to 40 ft in thickness in gneiss. These deposits are the source of much of the light-colored nephrite with a specific gravity of 2.9 to 3. It occurs as light- and dark-green and gray boulders in place in serpentine on D'Urville Island, New Zealand. Other occurrences are as boulders near Lake Baikal, Siberia; both as boulders and in place near Jordansmuhl, Silesia; at St. Michael, Alaska; and in New Guinea.

Jadeite occurs in boulders and in place with albite, forming light-colored layers in green serpentine in sandstone, in Mogoung, Upper Burma. Other localities are Sardinal, Costa Rica; Thibet; and Italy.

Jade (variety unnamed) was first discovered in China in the provinces of Shensi and Honan, but later deposits were found in Hunan and Kansu. After the eleventh century the Chinese supply was practically exhausted, and now most of the jade used in China comes from Myitkyina, Burma, and from Turkestan, the latter country furnishing practically all the white jade used in China.

Jade of the nephrite variety has been found in Wyoming near Lander. A small industry concerned with the production and polishing of the material has developed. The jade is found in pebbles and boulders and also in place. Some of the material has been shipped to China for carving. The better jade is reported to have sold for \$5 per pound, and exceptional specimens at as high as \$15. A large boulder weighing over a ton was polished on one side and shipped to Chicago for exhibition.

Jade has been known to occur in Alaska for centuries, and it has been used in a small way by the Eskimos. It appeared first on the American market in 1945. It is found on the north side of the Kobuk River. Mining claims have been located in the district, and selected material flown out to the market. Boulders have been collected from the bed of the river. Some of the material is of gem quality; the rest is suitable for carving. It is said to compare favorably with the nephrite of New Zealand.

Nephrite has been found in California in the southern part of the Santa Lucia Range in Monterey County. It has been found in large and small boulders and

in place in serpentine. In color it is said to vary from greenish gray to black. Some of the material is suitable for cutting.

Mining. Pebbles and boulders from rivers or streams are preferred material since they are less apt to contain hidden and incipient fractures than the mined stone. This source is exhausted in many areas and mining of outcrops and hill-side slopes has been common for many years. The crudest methods of hand labor and fire for shattering the rock are used. The mines are small; in Burma during the rainy season from May to December they are flooded. The gradual introduction of air drills and steam pumps is modernizing the industry, but many operations are too small and erratic in behavior to justify any appreciable investment in equipment. The percentage of recovery of valuable material is small, and large tonnages of waste and low-grade stone must be moved.

Utilization. The jade-carving industry is largely concentrated in China. By far the most important center is at Canton, with Peking second. Soochow and Shanghai, as well as most of the coast cities, are of relatively small importance. Most jade dealers and carvers refuse to handle more than one color of jade.

Those in Peking, Soochow, and Shanghai confine themselves almost exclusively to the white, used in making bracelets for men, belt buckles, vases, incense burners, and other large objects, while Canton has been for centuries the center of the green-jade industry and sets the styles for ornaments made from it.

Workmen and Tools. There are no jade manufacturers in Canton in the real sense of the word. Anyone may purchase the stone and send it to contractors to be cut into articles by skilled workmen. A rigid system of weighing and inspection prevents any stealing by either contractors or workmen during the process.

The contractor owns the shop and tools, solicits orders, and hires the jade workers, paying the latter by the piece and providing food and lodging. The contractor's payment is usually divided, so that he receives 60 per cent and the workmen 40 per cent.

There are about 10,000 workmen engaged in the jade industry in Canton, who are organized into four trade groups or unions, as follows: cutters, bracelet makers, plain carvers, and ornate carvers. Years of experience have produced highly specialized workers in the last-mentioned group, who receive about \$1 Mexican per day, while members of the other group receive \$0.40 Mexican per day. Simple tools instead of standardized machinery are used in the manufacture.

Market in Canton. How Sales Are Made. The green-jade importing business in Canton is handled by seven Cantonese firms, which buy direct from Burma. Members of these firms are stationed in Burma during the buying season, which occurs about May, when the stone is quarried. Once a year, usually at the beginning, the jade market is open for selling the imported stone, at which time the entire year's supply is to be disposed of. On the day before the sale the stones to be offered are exhibited, each piece bearing a number and cut so that the interior color is exposed. Prospective customers visit the exhibitions and make notes of the pieces they wish to purchase.

Secret bids are used in the sale. The auctioneer stands in the middle of the floor, wearing a coat with extra long and wide sleeves. When the number of the piece to be sold is announced, the buyers rush to the auctioneer, grasp his hand under the sleeve, and communicate their bids by means of standardized grips, a common method everywhere in China. These auctioneers have remarkable memories, taking bids from two buyers at the same time, and remembering all bids and bidders. Since he declares a piece sold as soon as a sufficiently high bid has been made, there is wild

rushing when a particularly fine piece is announced. However, this bid accepted by the auctioneer is subject to the approval of the importing house, which may order the piece resold.

There are two jade exchanges in Canton, and both are open every morning. One handles goods of the better quality, and the other inferior products. Each seller rents a booth in which to display his wares. The system of secret selling is also in use at these exchanges, and it is useless for any but experienced buyers to attempt to make purchases. Tourists purchase generally from the 40 or more jade stores in Canton, some of which operate on the one-piece basis. Most of them, however, "squeeze" as much as possible from every customer.*

The carving of jade is an art carried on by skilled craftsmen. Simple tools are used for the carving and polishing operations, and the industry has not been mechanized by western standards. Imitations of jade are sometimes cut from californite (variety of vesuvianite), massive green garnet, and other green stones.

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LAPIS LAZULI OR LAZURITE

Composition. Lapis lazuli or lazurite is a sodium, calcium, and aluminum sulfo- and chlorosilicate. It is represented by the formula $(\text{Na,Ca})_2\text{Al}_2\text{Al}(\text{NaSO}_4\cdot\text{NaS}_3\cdot\text{Cl})(\text{SiO}_4)_3$. Iron sulfide is nearly always present as pyrite.

General Description. Lapis lazuli usually occurs as irregular grains or masses, dark blue in color, and contains disseminated pyrite.

Physical Properties. *Hardness*, 5 to 5.5. *Specific gravity*, 2.4. *Melting point*, 3 in scale of fusibility. *Index of refraction*, 1.50. *Color*, deep blue, violet, and

* "The Chinese Jade Industry," *U.S. Bur. Foreign and Domestic Com., Commerce Reports*, May 1, 1922, pp. 314-315.

LAPIS LAZULI OR LAZURITE

greenish blue. *Streak*, white. *Luster*, vitreous to greasy. *Cleavage*, uneven fracture. *Transparency*, opaque to translucent. *Tenacity*, brittle.

Occurrence. Lapis lazuli is a contact metamorphic mineral occurring in crystalline limestones. The principal localities are Afghanistan; southern end of Lake Baikal, Siberia; Ovalle, Chile; and Cascade Canyon, San Bernardino County, Calif. It also occurs in several localities in India, namely in Badaksham, south of Firgamu in the Kokcha Valley; Sadmoneir; Bijour; Hazara; and Khelat. In the Kokcha Valley district the ore seems to be irregularly scattered through black and white limestones. It was formerly mined in underground workings by the aid of fire. When a nodule or pocket of ore was found it was outlined by chiseling and pried loose by crowbars. It was mostly marketed in the bazaars of India in Bokhara and China. Three varieties were distinguished by the miners: the *nili*, or indigo colored; the *asmani*, or sky blue; and the *sabzi*, or greenish colored. Lapis lazuli is a rare mineral in North America. It has been reported in San Bernardino County, Calif. The mineral occurs there, associated with pyrite, in a gray-blue color.

Uses. Formerly, ground lapis lazuli, or native ultramarine, was highly valued as a deep-blue pigment, but now it has been supplanted by artificial ultramarine. Massive lapis lazuli is in considerable demand as a gem stone and for other ornamental purposes. In the Orient it is turned and carved into bases, statues, bowls, and other ornaments; it is also used in mosaics and turned into beads. Strings of beads are often made from agate or other stones dyed blue and sold as "Swiss lapis." Such imitations can usually be detected by the absence of the small flecks of disseminated pyrite that are always present in true lapis. Light-blue lapis is sometimes changed to a darker blue or a blue violet by careful heating at a moderate temperature.

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LEUCITE

Composition. Leucite is a potassium aluminum silicate, having the formula $\text{KAl}(\text{SiO}_3)_2$ or $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$: K_2O , 21.52 per cent; Al_2O_3 , 23.33 per cent; SiO_2 , 55.15 per cent. Sodium may replace some of the potassium.

General Description. Leucite generally occurs as white or gray trapezohedral crystals or rounded grains disseminated through eruptive igneous rocks.

Physical Properties. *Hardness*, 5.5 to 6. *Specific gravity*, 2.5. *Melting point*, above 6 in scale of fusibility. *Index of refraction*, 1.508. *Color*, white, gray, yellowish, or reddish. *Streak*, white. *Luster*, vitreous to greasy. *Transparency*, translucent to opaque; rarely transparent. *Tenacity*, brittle. *Soluble* in acids,

the potash and alumina going into solution and leaving the silica in granular or powdery form.

Occurrence and Distribution. Leucite is found in disseminated grains and crystals in eruptive rocks, such as the lavas of Vesuvius, and in other basic eruptives, such as basalt. The principal associated minerals are sanidine, augite, nephelite, and olivine.

Leucite has been produced commercially only in Italy and the largest reserves of leucite in the world occur in that country, but there are also large deposits in the United States and in a few other countries.

Italy. According to Washington,⁷ leucitic lavas of seven volcanoes along the west coast of Italy, from Bolsena to Vesuvius, form the greatest accumulation of potash-rich silicate rocks known. These lavas, having an average potash content of about 9 per cent, contain at least 8,786,200,000 metric tons of potassium oxide.

The leucite occurs in the lavas in crystals varying greatly in size, "from that of a tennis ball or larger, through sizes of a walnut or a pea (these being more common), down to microscopic dimensions, so that often to the naked eye the rock does not appear to contain leucite." In places there are incoherent masses or tuffs consisting almost wholly of loose leucite crystals.

These leucite lavas are worked to some extent.

United States. The Leucite Hills of Sweetwater County, Wyo., have long been of scientific interest as a possible source of potash and alumina. Here in southwestern Wyoming in the vicinity of Zirkel Mesa, 44 miles northeast of Green River, are exceedingly large deposits of the volcanic rock, wyomingite. This rock contains about 50 per cent leucite, 15 per cent phlogopite mica, 12 per cent diopside, 15 per cent kataphorite (iron-bearing hornblende), and 8 per cent glass and apatite. Schultz and Cross⁵ have estimated that there is a total of about 2 billion tons of wyomingite in these deposits, containing about 10 per cent each, or 200 million short tons each, of pure potash and alumina.

Utilization. Leucite has not been used commercially, except for the minor use of Italian leucite directly as a fertilizer material and as a minor source of alum. During the First World War several attempts were made to extract potash from Wyoming leucite, but little if any commercial production resulted.

Recently there has been renewed interest in the commercial production of potash from Wyoming leucite due to the commercial development of the very extensive trona beds at Westvaco, Wyo.,* 20 miles west of Green River, and the development by the U.S. Bureau of Mines of a process⁴ for reacting wyomingite with trona to produce pure potassium carbonate and pure sodium carbonate. This reaction depends upon the base-exchange property of leucite. With the close juxtaposition of the trona and leucite, with the trona development in strong hands, and with process water, fuel, and rail transportation close at hand, the outlook for the development of these deposits seems bright.

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* See page 497, Sodium Salts.

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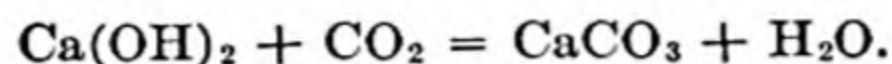
LIMESTONE AND LIME

Lime has been produced since the earliest historic times and in nearly every country. It was the first manufactured cementing material known, and its use permitted the development of masonry in walls and buildings. Lime mortars of great age still exhibit excellent strength and permanence. It was the first plastering medium extensively used to produce smooth interior walls. Its value as a soil conditioner and plant fertilizer was recognized at an early date, and oystershell was collected in tonnage in many coast areas for this purpose where stone was not available. The structural importance of lime has declined due to the rise of competitive materials possessing greater convenience in use. Portland cement is used in most mortars, with addition of some lime to increase plasticity, and gypsum plaster has nearly displaced lime for interior walls. The commercial importance of lime would have receded to a comparatively small figure if it had not been for the rise of the chemical industries. The successful application of chemistry to the problems of industry has become the most conspicuous activity of the present century. Lime is the cheapest alkali, one of its many advantages to the chemical industries. It has become an essential constituent in dozens of activities of primary importance in the modern world.

Definition of Lime. By proper chemical nomenclature lime is calcium oxide (CaO), but, commercially, lime is understood to mean the product of complete calcination of a "limestone," which may vary from pure calcium carbonate (CaCO_3) to pure dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$). Thus, commercial lime may contain as high as 45 per cent magnesium oxide (MgO), as well as such impurities as silica, iron oxide, and alumina. The term is used loosely at times to apply to calcareous material.

Lime is sold in two forms: (1) quicklime, CaO , and (2) hydrated lime, Ca(OH)_2 . Hydrated lime is formed from quicklime by adding the requisite amount of water. When hydrated lime is exposed to the air for some time, it gradually absorbs carbon dioxide (CO_2) from the air and "air-slakes," or reverts to its

original form of calcium carbonate (CaCO_3). The same reaction takes place when lime plasters are exposed to the atmosphere. The reaction is



The reaction takes place slowly, and the water evolved tends to keep the walls wet. This has contributed to the displacement of lime plaster by gypsum.

Commercial limes are classified according to their relative content of CaO and MgO as follows:

High-calcium lime: not less than 90 per cent CaO .

Calcium lime: not less than 85 per cent nor more than 90 per cent CaO .

Magnesian lime: Not less than 10 per cent nor more than 25 per cent MgO .

High-magnesian lime: not less than 25 per cent MgO .

Total impurities (exclusive of carbon dioxide) should not be over 5 per cent in selected lime or $7\frac{1}{2}$ per cent in run-of-kiln lime.

Theoretically, 1 ton of pure calcium limestone should yield about 0.54 ton of pure lime (CaO), and 1 ton of pure dolomitic limestone should yield about 0.52 ton of dolomitic lime ($\text{CaO}\cdot\text{MgO}$).

Quarrying Methods. Limestone deposits vary so greatly in their modes of occurrence, and quarrying methods differ so greatly, that it is impossible to give generalized descriptions that will cover all operations. Only the fundamental principles will be here discussed.

The objects of limestone quarrying for lime manufacture are (1) to obtain stone of as high quality as possible, that is, stone low in impurities, particularly iron; (2) to maintain uniformity of composition; (3) to obtain the greatest possible proportion of the stone in the coarser sizes, that is, 4 to 8 in.; (4) to maintain a steady production under all conditions; and (5) to quarry and deliver the stone to the kilns as cheaply as possible.

Since variations in the composition of limestone are usually greater between different beds than between the various parts of the same bed (within a small area), it is usually preferable to work as thick a bed as possible and to follow that bed either horizontally or along the dip, rather than work across several different beds. Local conditions, however, may make this difficult or unduly expensive.

Most limestone deposits are covered by a variable thickness of overburden consisting of clay, sand, and gravel or impure stone, which must be removed before the good stone is quarried. Many methods of stripping are used, depending upon the nature and amount of the overburden, size of the operation, etc. Unconsolidated overburden may be removed by hand shovels and carts, by ploughs and scrapers, by steam shovels, by various types of mechanical excavators, or by hydraulicking. Rock overburden must be removed by drilling and blasting. The removal of heavy overburden or of clay in seams and pockets may be very expensive. Where the overburden is excessive, particularly rock overburden, the stone may be removed by underground mining methods.

After the stripping is removed, the stone must be drilled and blasted. The problem here is different from that in cement rock quarries, for greater care must be taken in selecting the rock. For this reason in many quarries churn-drill-hole blasting and steam-shovel loading are not used. More often, probably, the rock

is drilled and blasted in benches, usually not over 20 ft high. If the rock is sufficiently pure and homogenous so that a high quarry face may be maintained, churn-drill-hole blasting is usually cheaper.

After the stone is shot down the methods of handling the rock differ, depending upon whether hand loading or steam-shovel loading is used. If the rock contains impurities that must be removed by hand sorting, the large blocks are broken up, by mud-cap or block-hole blasting and hand sledging, into pieces easily handled by one man. The impure rock is then separated out and the good stone loaded into quarry cars or carts by hand or by the use of forks, to eliminate small pieces or spalls. If no sorting is needed, the cheapest method of loading, where the daily production is over 200 or 300 tons, is by power shovels. If shovel loading is used, the rock need only be broken small enough to go into the shovel dipper, provided that proper crushing and screening equipment is available at the plant. If a small crusher is used, the stone must be broken in the quarry small enough to enter the crusher opening. If no crushing and screening equipment is provided, the stone must be broken down by hand to "one-man" size, and much of the efficiency of shovel loading is lost.

Transportation problems include taking the stone out of the quarry, taking it from the quarry to the kilns, and elevating it to the top of the kilns. Methods of transportation vary greatly, depending upon local conditions. The following methods are in use: wheelbarrows; horse-drawn carts; cars drawn by horse, cable, or locomotive; cars or buckets on aerial cableways; and pans or skips hoisted by derricks. Frequently, two or more of these methods are used in combination.

In recent years the underground mining of limestone has become increasingly important where large tonnage, low-cost operations are needed.¹⁶ A good example of this is the limestone mine of the Columbia Chemical Division of the Pittsburgh Plate Glass Co. at Barberton, Ohio,^{13a} probably the deepest limestone mine in existence. Here a limestone bed, 345 ft thick, is opened by two vertical shafts, 16 by 7 ft in the clear, to a depth of nearly 2,300 ft. A room-and-pillar system of mining is used with rooms 40 ft wide by 50 ft high opened on 80-ft centers. For rock loading in the rooms 2½-yd caterpillar-mounted electric shovels are used and hauling is done by large 8- to 16-ton diesel-powered trucks. Primary crushing is done underground, and fully automatic skip loading is used. The plant was designed for a capacity of 300 tons per hr.

When the stone reaches the kilns, it may be charged directly into them, provided that it has been sized at the quarry. If power-shovel loading is used, it is commonly necessary to crush the stone to a maximum size of about 8 in. and to remove the fine sizes by screening. Where there is a market for crushed stone, as is often the case, all the stone smaller than 3 or 4 in. may be recrushed and sized by screening into the various commercial sizes of crushed stone. The disposition of stone by size to the most profitable market may become a matter of prime importance in deciding the success or failure of an operation.

Lime Burning. The object of lime burning is to disassociate the carbonates, liberating carbon dioxide and leaving a residue of oxides, called quicklime. The disassociation temperature of calcium and magnesium carbonates is indefinite, depending upon conditions. Calcium carbonate is broken down completely

around 900°C, and magnesium carbonate around 550°C. The reaction starts at a much lower temperature, possibly 200° less than the maximum indicated. Magnesite and magnesium limestones require less heat during calcination, and this is reflected in an improved fuel ratio in kilns operating with these materials. Temperatures should be controlled to produce a soft-burned, active lime, and extensive research has been applied to the study of conditions producing a uniform high-quality product.³ If temperatures are too low the lime will have a core of the original carbonates; if too high, an overburned product will result with low activity due to fusion and reaction of silicates and other impurities present in the original stone.

Lime has been burned in many types of kilns, but most of the kilns in use in the United States today may be placed in one of four general classes, namely, the field kiln, the pot kiln, the shaft kiln, and the rotary kiln.

A field kiln is the crudest type, frequently built by farmers to provide a supply of lime for the soil. It may be built against a hillside so that it can be loaded conveniently from the top side. Fuel, often wood, and rock are introduced in alternate layers, and the charge is ignited from the bottom. The charge is allowed to burn out, and the contents are then extracted from the base of the kiln. The operation is slow and inefficient and produces an indifferent product, which may be perfectly suitable for its intended use.

The pot kiln is a more permanent vertical-shaft kiln charged with stone and fuel in alternate layers but operated continuously. Shaft kilns have been built in many designs, often in rows provided with track running at the top level so that they may be loaded with stone dumped from cars direct from the quarry. They are fired with wood, coal, or producer gas. The choice of fuel depends upon the variety available locally and the economy of its use.

The introduction of the rotary kiln has produced many changes in the lime industry. The kiln is identical in general construction with those used in the portland-cement industry. Kilns of great length, up to 500 ft, are in operation. The rotary kiln calcines small stone, the disposal of which was a serious problem and the cause of great waste before its introduction.⁵ The stone is sized about 2½ in. maximum to 1 in. minimum. Some variation is allowable, depending upon local conditions. A size ratio of 2½:1 has been found desirable. Gas, oil, and coal are used as fuel. The use of powdered coal may be objectionable due to the introduction of ash as a contaminating agent. Calcining conditions may be controlled by adjustment of the flame and the rpm at which the kiln is turning over. The rotary kiln has the advantage of ability to handle small stone and great capacity. It requires a high initial investment and can be operated economically only at a fairly high percentage of capacity.

The Ellernan calciner is a more recently designed kiln capable of calcining small stone.¹² One unit has been designed to handle stone from ¼ to ¾ in. in size with a capacity of 6 to 12 tons of lime per 24 hr, and a second for stone ½ to 1½ in. in size with a capacity of 12 to 25 tons of lime per day. Such kilns in operation in the West were first used for the production of high-purity lime for the manufacture of calcium carbide. The calciners are continuous in operation with a constant feed of raw stone from a feed hopper located above the calcining

chamber and a continuous discharge of lime below. Temperatures are controlled by regulation of fuel, oil, or producer gas and draft. Little labor and a minimum of supervision are required. The use of tunnel beams in the calcining chamber permits the hot gases to pass through the small stone, calcining it, and then continuing to preheat the raw stone. Exhaust gases are discharged at temperatures varying from 425 to 500°F. Lime is at ordinary temperature. Thermal efficiency, therefore, is high. Units may be installed in multiples to produce any desired daily tonnage of lime.

A new method of calcining fine material is of recent interest.^{9,13} This is based on fluidization, which Kite and Roberts define as follows: "Fluidization is the unit operation in which a mass of finely divided solids is maintained during treatment in a turbulent dense state by being dispersed in an upwardly moving gas stream which imparts to the mass a turbulence resembling that of boiling liquid."⁹ Research conducted by the Dorr Co. in cooperation with the New England Lime Co. has shown that finely divided limestone, -6 mesh, +80 mesh, may be calcined to lime in such a condition. The fine stone is fed to a specially designed reactor in which it is preheated, calcined in a turbulent condition, and then cooled. Oil, gas, or coal may be used as a fuel. Close control of the operation permits the production of a soft lime. The process is particularly adapted to the finely precipitated calcium carbonate produced as a by-product in the manufacture of paper and beet sugar and the softening of water.

The quicklime produced by any calcining operation will combine readily with water to form a hydrate. This reaction is accompanied by the liberation of heat, which, if confined, may be sufficient to ignite combustible material. Quicklime must therefore be protected in storage and shipment from wetting or exposure to excessively humid atmospheres.

Hydrated Lime. For many purposes quicklime must be hydrated or "slaked" before it is used. This process involves adding water to quicklime (CaO), forming hydrated lime or calcium hydroxide [$\text{Ca}(\text{OH})_2$]. In the past this was always done "on the job" immediately before use, but unless the slaking was done by an experienced workman there was always the danger of "burning" the lime by local overheating. To meet this and other disadvantages of the use of lump quicklime, considerable lime is now hydrated at the lime plant and sold as a dry powder.

The manufacture of hydrated lime involves the following steps: crushing the lump quicklime, hydrating, removing the coarse impurities by screening or air separation, and packing.

The lump lime is crushed to produce greater surface for the action of water. In some plants the lime is crushed only to $\frac{1}{2}$ or 1 in., but in others it is ground as fine as 80 per cent through 50 mesh. Various types of crushers and grinders are used.

Several types of mechanical hydrators are used, but in all of them the crushed lime is agitated with water in definite proportions and the product is a completely hydrated lime in the form of a dry powder. The process may be continuous or intermittent.

After the lime is hydrated, it is screened or put through an air separator to remove the coarse impurities. Sometimes a Raymond pulverizer equipped with

TABLE 1. LIME (QUICK AND HYDRATED) SOLD BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY USES

Use	1945			1946		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Agricultural.....	373,410	\$2,906,844	\$7.78	384,658	\$3,151,613	\$8.19
Building:						
Finishing lime.....	229,034	\$2,131,458	\$9.31	347,237	\$3,535,208	\$10.18
Mason's lime.....	241,802	\$2,111,177	8.73	389,003	3,996,480	10.27
Prepared masonry mortars.....	27,693	193,274	6.98	45,631	352,950	7.73
Unspecified.....	51,018	473,455	9.28	63,733	742,060	11.64
	549,547	\$4,909,364	\$8.93	845,604	\$8,626,698	\$10.20
Chemical and industrial:						
Alkalies (ammonium, potassium, and sodium compounds).....	a	a	a	2,572	\$ 21,528	\$8.37
Asphalts and other bitumens.....						
Bleach, liquid and powder ^b	24,712	\$192,041	\$7.77	13,872	124,239	8.96
Brick, sand-lime and slag.....	12,641	108,974	8.62	18,667	164,049	8.79
Brick, silica (refractory).....	15,322	139,105	9.07	14,665	133,153	9.08
Calcium carbide and cyanamide.....	364,944	2,534,625	6.95	377,694	2,806,965	7.43
Chromates and bichromates.....	36,252	239,812	6.62	28,378	201,700	7.11
Coke and gas (gas purification and plant by-products).....	31,173	221,576	7.11	25,675	198,976	7.75
Explosives.....	15,531	124,933	8.04	1,579	14,399	9.12
Food products:						
Creameries and dairies.....	7,298	69,792	9.56	3,232	37,546	11.62
Gelatin.....	5,027	38,091	7.58	5,270	44,186	8.38
Stock feed.....	10,798	109,718	10.16	8,503	114,564	13.47
Other ^c	4,584	43,774	9.55	9,333	90,992	9.75
Glassworks.....	220,853	1,631,019	7.39	248,693	1,949,215	7.84
Glue.....	9,148	70,114	7.66	8,179	67,786	8.29
Grease, lubricating.....	2,068	15,282	7.39	2,722	22,346	8.21
Insecticides, fungicides, and disinfectants.....	82,507	713,465	8.65	96,457	888,114	9.21
Magnesia (85 per cent).....	23,647	210,544	8.90	26,376	246,405	9.35
Medicines and drugs.....	7,897	53,560	6.78	10,517	77,345	7.35
Metallurgy:						
Nonferrous smelter flux.....	7,442	59,695	8.02	9,560	76,030	7.95
Steel (open-hearth and electric furnace flux).....	1,064,005	7,136,870	6.71	874,243	6,390,713	7.31
Ore concentration ^d	342,742	2,316,172	6.76	205,541	1,585,993	7.72
Wire drawing.....	16,645	147,508	8.86	13,527	125,111	9.25
Other ^e	11,868	94,879	7.99	41,073	348,467	8.48
Paints.....	18,950	136,215	7.19	25,598	239,113	9.34
Paper mills ^b	510,832	3,740,694	7.32	565,839	4,489,033	7.93
Petroleum refining.....	53,176	448,091	8.43	48,387	446,532	9.23
Rubber manufacture.....	7,170	51,133	7.13	3,193	26,516	8.30
Salt refining.....	1,884	13,103	6.95	4,384	32,067	7.31
Sewage and trade-wastes treatment.....	71,496	561,649	7.86	65,514	563,037	8.59
Soap and fat.....	5,221	33,246	6.37	2,897	20,572	7.10
Sugar refining.....	24,584	279,843	11.38	26,887	345,687	12.86
Tanneries.....	81,213	613,493	7.55	80,182	649,290	8.10
Varnish.....	364	3,460	9.51	302	3,766	12.47
Water purification.....	402,158	3,034,810	7.55	431,772	3,565,522	8.26
Wood distillation.....	1,265	11,624	9.19	3,830	29,660	7.74
Undistributed ^f	25,032	235,843	9.42	73,614	704,753	9.57
Unspecified.....	289,829	2,053,796	7.09	305,728	2,307,039	7.55
	3,810,288	\$27,488,549	\$7.21	3,684,455	\$29,152,499	\$7.91
Refractory lime (dead-burned dolomite)	1,187,334	10,613,711	8.94	1,077,983	10,101,707	9.37
Total lime ^g	5,920,579	\$45,918,468	\$7.76	5,992,700	\$51,032,517	\$8.52
Hydrated lime included in above distribution.....	1,355,028	\$11,422,254	\$8.43	1,648,369	\$15,083,399	\$9.15

^a Included under Undistributed.

^b Bleach used in paper mills excluded from Bleach and included with Paper mills.

^c Includes chocolate, cocoa, fruit juices, phosphate baking powders, and unspecified food products.

^d Includes flotation, cyanidation, bauxite purification, and magnesium manufacture.

^e Includes mold coating and unspecified metallurgical uses.

^f Includes acid neutralization, alcohol, calcium carbonate (precipitated), cement manufacture, polishing compounds, retarder, sulfur, textiles, and wool pullers; in addition, alkalies in 1945 and asphalts and other bitumens in 1946.

^g Includes lime used by producers (captive tonnage) as follows—1945: 368,572 tons, valued at \$2,216,373; 1946: 328,827 tons, \$2,216,551.

LIMESTONE AND LIME

a throwout device and air-separating equipment is used. This equipment grinds the hydrate, throws out the coarse unburned "core," and air-floats the product. The hydrate is stored in bins to "age" and is then packed, by hand or by mechanical packers, in bags for shipment.

The physical behavior of the lime may be altered by control during hydration, and pressure hydrators are used to increase the plasticity of the hydrate.

TABLE 2. HYDRATED LIME SOLD BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY USES

Use	1945			1946		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Agricultural.....	252,881	\$ 2,078,924	\$ 8.22	271,172	\$ 2,251,936	\$ 8.30
Building.....	434,026	3,762,343	8.67	639,549	6,275,938	9.81
Chemical and industrial:						
Bleach, liquid and powder.....	9,275	\$ 79,422	\$ 8.56	5,468	\$ 48,121	\$ 8.80
Brick, sand-lime and slag.....	*	*	*	3,270	31,395	9.60
Brick, silica.....	12,295	116,618	9.48	12,405	115,810	9.34
Coke and gas.....	1,819	14,362	7.90	1,124	9,888	8.80
Food products.....	13,889	138,138	9.95	15,215	157,333	10.34
Glass.....	2,834	23,473	8.28	*	*	*
Insecticides.....	60,233	538,828	8.95	72,910	687,638	9.43
Metallurgy.....	37,960	319,628	8.42	39,706	349,430	8.80
Paints.....	7,590	61,050	8.04	10,406	101,657	9.77
Paper mills.....	30,040	247,508	8.24	39,852	330,086	8.28
Petroleum.....	34,857	329,502	9.45	29,349	306,250	10.43
Sewage.....	29,241	242,681	8.30	33,157	287,798	8.68
Sugar.....	15,717	193,637	12.32	16,477	242,003	14.69
Tanneries.....	44,841	352,624	7.86	44,567	372,910	8.37
Water purification.....	181,350	1,497,703	8.26	226,939	2,021,579	8.91
Other uses.....	186,180	1,425,813	7.66	186,803	1,493,627	8.00
	668,121	\$ 5,580,987	\$ 8.35	737,648	\$ 6,555,525	\$ 8.89
Total hydrated lime.....	1,355,028	\$11,422,254	\$ 8.43	1,648,369	\$15,083,399	\$ 9.15

* Included under Other uses.

Production of Lime. In 1948, 7,263,976 tons of lime, quick and hydrated, were sold in the United States, valued at \$75,162,879. This is not the total production, since captive plants owned by the companies consuming the lime are not included. Lime was produced in over 40 states. Ohio, Pennsylvania, Missouri, Alabama, and Illinois produce nearly two-thirds the total output of the country. Although limestone is widely distributed, a large percentage of the total is not suitable for the manufacture of lime, particularly chemical lime, which is now so large a part of the industry. Raw stone suitable for conversion to chemical lime should be either a pure calcium carbonate or, in the case of dolomite, a pure calcium magnesium carbonate. Pure material scarcely exists, and it is necessary to use the nearest approximation economically available. Limestones or dolomites with

less than 2 per cent impurities are by no means abundant and frequently not located in the industrial areas with large lime-consuming capacity. In 1948, 7,263,976 tons of lime were sold valued at \$75,162,879.

Consumption of Lime. Lime is consumed in three major markets: agriculture, building, and chemical. Its importance and potential markets are best illustrated in Tables 1 and 2. These tables represent sales and are not truly representative of the role played by lime in industry.

Prices. Quicklime and hydrate are low-priced commodities and sell in a range of from \$8 to \$10 per ton. Large consumers purchasing on annual contract effect some economies.

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LITHIUM MINERALS

Amblygonite, Lepidolite, and Spodumene

The principal lithium minerals, together with their content of lithia (Li_2O), are listed below:

Name	Lithia content, per cent		
	Theoretical	Average	Range
Amblygonite.....	10.1	9	3.5-10
Spodumene.....	8.1	4-7	1.2-7.6
Lepidolite.....	6.43	4	1.13-6.06
Dilithium sodium phosphate.....	22.6	20	19-21

Other rare or less common lithium-bearing minerals are *triphyllite*, a phosphate of iron and lithium containing about 9 per cent lithia; *lithiophilite*, a phosphate of manganese and lithium containing about 9 per cent lithia; *petalite*, a silicate of aluminum and lithium, containing theoretically 4.9 per cent lithia; *zinnwaldite*, a micaceous mineral resembling lepidolite, but containing about 10 per cent iron oxide with 3 to 5 per cent lithia. All these latter minerals have been occasionally mined, when found in sufficient quantities, as sources of lithium.

Production. Lithium minerals have been mined sporadically and on a small scale in various countries for probably at least 75 years, but accurate production statistics are unavailable except for recent years and then only from the United States. About 1886, France began to produce amblygonite, but lithium minerals had previously been mined in Bohemia and Saxony (principally zinnwaldite). Petalite has been mined in considerable quantities at Uto, Sweden. About 1898, spodumene was mined regularly in South Dakota, and a few years later lepidolite production began in California; then amblygonite was developed in both California and South Dakota. Later, substantial tonnages of lepidolite were found near Dixon, N.Mex. A small quantity of lithium ore has been mined or deposits reported in a few other states, namely, Massachusetts, Maine, Connecticut, and Colorado. The discovery of large tonnages of spodumene in North Carolina and the development of a process for the recovery of lithium salts from the brines of Searles Lake, Calif., have opened huge reservoirs of lithium for industrial use and have altered all previous estimates as to reserves for future production.

Prewar Germany was a small producer of lithium products from imported ores,

largely amblygonite from Tsumeb, South-West Africa. During the war production came from tungsten-tin mill tailings in Zinnwald, Erzgebirge, near Freiberg, Germany, which contained 0.2 to 0.5 per cent lithium in the form of zinnwaldite.¹⁸

Large deposits of high-grade lepidolite occur in Karibib, South-West Africa. It is estimated that several hundred thousand tons of material are present, recoverable by open-cut mining. It contains 4 per cent lithium oxide and 2 per cent rubidium oxide. Petalite and amblygonite in considerable tonnage are also found in this area.⁵

AMBLYGONITE

Composition. Amblygonite is a phosphate of lithium and aluminum with fluorine and usually contains combined water. Its formula, when the substance is pure, is $\text{Li}(\text{Al}\cdot\text{F})\text{PO}_4$, or $\text{Al}_2\text{O}_3\cdot\text{P}_2\text{O}_5\cdot 2\text{LiF}$. Its theoretical content is Li_2O , 10.1 per cent, but often sodium replaces part of the lithium. The actual content of Li_2O varies from 3.5 to 10 per cent and usually averages about 9 per cent.

General Description. Amblygonite usually occurs as coarse, white, cleavable aggregates or rounded masses; sometimes in large indistinct crystals. It contains the highest percentage of lithia of the common lithium minerals and is the most valuable ore for the manufacture of lithium chemicals.

Physical Properties. *Hardness*, 6. *Specific gravity*, 2.88 to 3.09. *Melting point*, 2 in scale of fusibility. *Index of refraction*, 1.579 to 1.597. *Color*, usually white, sometimes with brown, yellow, green, or blue tints. *Streak*, white. *Luster*, vitreous to pearly. *Cleavage*, perfect in one direction, imperfect in two or three others; fracture uneven. *Transparency*, translucent to opaque. *Tenacity*, brittle.

Occurrence. Amblygonite occurs chiefly in pegmatites associated with other lithium minerals, such as spodumene and lepidolite; with other phosphates, such as apatite and triplite; and with the typical pegmatite minerals.

The most important commercial locality is in the Harney Peak district near Keystone, *South Dakota*. Here, with its associate spodumene, it is obtained commercially from open pits by simple quarrying methods. Practically all the present amblygonite production comes from this district.

In *California* amblygonite is commonly associated with lepidolite in the pegmatites of the Pala district, San Diego County. It has also been reported at Dixon, *New Mexico*.

In *France* amblygonite has been mined to a slight extent at Montebrias in Crease. In northwestern *Spain* the San Finx tin mine, in the province of Caceres, has been a small but fairly steady producer.

Because of its high lithia content and relative ease of solubility amblygonite has been considered the most desirable mineral for the manufacture of lithium salts.

Near Karibib and Tsumeb, South-West Africa, are important deposits of amblygonite and petalite that have been commercial producers for many years.^{4,19}

LEPIDOLITE

Composition. Lepidolite, lithium mica, is a complex silicate of aluminum, potassium, and lithium with fluorine and water, having the formula $(\text{Li},\text{K})_2$ -

LITHIUM MINERALS

$(F,OH)_2Al_2Si_3O_9$ or $12SiO_2 \cdot 3Al_2O_3 \cdot 3Li_2O \cdot 2K_2O \cdot 8F$ or $Al_2O_3 \cdot 3SiO_2 \cdot 2(K,Li)F$. It contains small quantities of iron, manganese, and sodium; some varieties contain rubidium and cesium. The theoretical content of lithia (Li_2O) is 6.43, but the actual content varies from 2 to 6 per cent. Following is an analysis of a lepidolite mined at Pala, San Diego County, Calif.:

	<i>Per Cent</i>
Silica (SiO_2).....	50.18
Alumina (Al_2O_3).....	22.81
Lime (CaO).....	0.18
Magnesia (MgO).....	0.16
Lithia (Li_2O).....	4.92
Rubidium oxide (Rb_2O).....	0.97
Cesium oxide (Cs_2O).....	0.30
Potash (K_2O).....	17.48
Fluorine (F).....	1.20
Manganese oxide (Mn_2O_3).....	0.41
Moisture (H_2O).....	2.10
	<hr/> 100.71

General Description. Lepidolite usually is found as a compact aggregate of very small scales, forming scaly, granular masses, but occasionally in short prismatic crystals; rarely in large plates or sheets. Its color is commonly pink or lilac. Most occurrences of lepidolite are isomorphous mixtures of the pure mineral with muscovite, thus accounting for a lithia content lower than the theoretical amount.

Physical Properties. *Hardness*, 2 to 4. *Specific gravity*, 2.8 to 2.9. *Melting point*, 2 in scale of fusibility. *Index of refraction*, 1.560 to 1.605. *Color*, commonly pink or lilac; also red, purple, gray, white, yellow, or brown. *Streak*, white. *Luster*, pearly. *Cleavage*, perfect basal. *Transparency*, translucent to transparent. *Tenacity*, sectile.

Occurrence. Lepidolite commonly occurs in pegmatite dikes, also in granites and gneisses. It usually is a product of pneumatolytic action and is commonly associated with tourmaline (especially rubellite), spodumene, amblygonite, feldspar, quartz, and muscovite.

It has been produced commercially from the gem pegmatites near Pala, San Diego County, Calif.; from near Dixon, N.Mex.; from the Keystone, S.Dak., area; and from near Canon City, Colo. At Wakefield, Canada, lepidolite has been found in sheets up to a foot in diameter. On Mount Hradisko, Moravia, Germany, a body of lepidolite 6 ft thick is reported. It is also found at Uto, Sweden; in Karibib, South-West Africa;⁵ in Western Australia; and elsewhere.

SPODUMENE

Composition. Spodumene is lithium aluminum silicate [$LiAl(SiO_3)_2$ or $Li_2O \cdot Al_2O_3 \cdot 4SiO_2$]. It usually contains sodium, iron, calcium, or manganese. Its theoretical composition is Li_2O , 8.1 per cent; Al_2O_3 , 27.4 per cent; SiO_2 , 64.5 per cent. Its actual lithia (Li_2O) content varies from 1 to 7.6 per cent.

General Description. Spodumene generally occurs as white or greenish-white, prismatic, monoclinic crystals often of great size. *Hiddenite* is a yellow-green or

emerald-green variety found in small transparent crystals at Stony Point, Alexander County, N.C. *Kunzite*, is a transparent, pale, lilac-pink variety found in the vicinity of Pala, San Diego County, Calif. Kunzite is noted as a gem stone and for its strong phosphorescence when exposed to radioactive substances, such as radium, to electric discharges, to ultraviolet light, or to X-rays. Spodumene easily alters to albite and muscovite.

Physical Properties. *Hardness*, 6 to 7. *Specific gravity*, 3.1 to 3.2. *Melting point*, both 1223°C and 1417 to 1428°C are given. *Index of refraction*, 1.660 to 1.676. *Color*, white, pale green, yellow to emerald green, pink, and lilac. *Streak*, white. *Luster*, vitreous to pearly. *Cleavage*, perfect prismatic, also easy parting parallel to orthopinacoid; uneven to splintery fracture. *Transparency*, opaque to transparent. *Tenacity*, brittle.

Occurrence. Spodumene usually occurs in or associated with pegmatite dikes, together with quartz, feldspar, mica, tourmaline, beryl, garnet, lepidolite, etc.

The most important locality in the United States for common spodumene is the Etta mine and vicinity near Keystone, Pennington County, S.Dak. Here very large crystals, up to 6 ft thick and 42 ft long, are found in abundance in a very coarsely crystallized pegmatite associated with amblygonite, cassiterite, and the typical pegmatite minerals. Several open cuts have been developed in this district, and the spodumene crystals, resembling logs, have been removed by simple quarrying methods.

In Massachusetts spodumene is found at Huntington, Chester, Chesterfield, Goshen, Leominster and Sterling. A small quantity was mined in 1889 for export.

The variety kunzite is found in small quantities in pegmatites near Pala, San Diego County, Calif., associated with lepidolite, amblygonite, tourmaline, beryl, and the typical pegmatite minerals.

Commercial interest in the spodumene deposits of North Carolina was noted first in 1938. Exploration disclosed the presence of a surprisingly large area mineralized with spodumene. A pegmatitic area was found to extend from Grover on the South Carolina line to Lincolnton, 25 miles to the northeast. Kings Mountain, N.C., is centrally located in the district. Many pegmatite dikes are present, some of which contain spodumene. Hess¹¹ states that the pegmatites are simple in mineralogical composition, composed essentially of feldspar, quartz, muscovite, spodumene, and minor amounts of tourmaline. Individual crystals vary in size, a large one being 2.5 ft in length; the average, finger size. No exceptionally large crystals, such as are found in South Dakota, have been encountered. Parts of the pegmatite contain 15 per cent or more spodumene. Some pegmatites have been traced for as much as $\frac{1}{2}$ mile, showing a width of from 20 to 100 ft. The potential reserve, therefore, is very large, being a matter something in excess of a million tons of mineral. The spodumene averages 6.51 per cent lithium oxide and has an iron content varying from 0.18 to 0.5 per cent Fe_2O_3 . The large size of this deposit suggests the use of mechanized mining and recovery of the mineral by milling methods. The limited markets for lithium compounds to date have not encouraged such a procedure. The possibility of the use of flotation has been investigated.¹² Fraas and

Ralston⁷ have suggested the use of decrepitation as a means of separation of spodumene from its gangue minerals. In this process the ore is heated to about 1000°C, causing the spodumene to invert from alpha to beta form. This becomes relatively soft and pulverulent. Gentle grinding under close control converts the spodumene to fine size so that it can be concentrated by particle-size separation and removed from the associated quartz and feldspar, which remain comparatively unchanged during the process. Under the impetus of wartime demands these North Carolina deposits became a major producer in 1943. Postwar production has been negligible.

Large deposits of spodumene were explored during the Second World War on the Winnipeg River, Manitoba, Canada.* These deposits near Lamprey Falls, Bernic, Cat, and Herb Lakes are reported to contain at least 5 million tons of lithium ore, some of which runs 6 to 7 per cent Li_2O , but they were too remote for profitable development at the time.

By-product from Searles Lake, Calif. Lithium is produced as a by-product in the treatment of the brines of Searles Lake for the recovery of potassium salts (see Potash). In 1923, $\text{Li}_2\text{Na}(\text{PO})_4$ was detected in a scale that formed on heating tubes of brine evaporators. This was found to contain about 20 per cent Li_2O , or a much higher lithia content than any ore mined for the production of lithium. Fifteen years later recovery on a commercial basis was begun. According to Gale⁹ this was considered a by-product until 1942, when wartime demands elevated it to the rank of coproduct. The brine, with a content of 35 per cent dissolved solids, contains LiCl to the amount of 0.033 per cent. The 17,500 tons of brine pumped to the plant per day contain some 10 tons of Li_2NaPO_4 or 2 tons of Li_2O . The dilithium sodium phosphate accumulates with burkeite, a double salt of sodium carbonate and sodium sulfate, which is a residual product from evaporation processes. This material is prepared properly for flotation until it has about 0.2 per cent solids in suspension. This liquid is conducted to flotation cells, and the lithium product floated and collected as a concentrate. This is washed with hot water, filter pressed and dried, and bagged for shipment. It contains from 19 to 21 per cent Li_2O .

Foreign Countries. Canada first produced lithium ores at Bernic Lake in 1937. Lepidolite and spodumene are present. Ores have been reported near Falcon Lake, 85 miles east of Winnipeg, and in Quebec. Spain and Portugal were at one time important producers for the European market. Production in recent years is not believed to be significant. France has been a small but consistent producer for some time. Possibly the most active mining outside of the United States has been carried on in South-West Africa. Both lepidolite and amblygonite are produced. The entire output is exported to Europe and the United States.

Production. Production of lithium ores in the United States as reflected by shipments is shown in the table on page 293.

Prices. In the summer of 1950 amblygonite was quoted at \$110 per ton, air-floated material in carload lots; lepidolite, at \$80 per ton, powdered in carloads, 4 per cent Li_2O ; spodumene, \$6 to \$8 per unit Li_2O , on 6 per cent grade in carloads; lithium, 98 to 99 per cent, \$15 per pound. Dilithium sodium phosphate has been reported as sold around \$230 per ton.

* U.S. Bur. Mines, *Mineral Trade Notes*, February, 1947, pp. 48-49.

SHIPMENTS OF LITHIUM ORES AND COMPOUNDS FROM MINES IN THE UNITED STATES,
1935 TO 1939 (AVERAGE) AND 1942 TO 1946

Year	Ore, short tons	Value	Li ₂ O, short tons	Year	Ore, short tons	Value	Li ₂ O, short tons
1935-1939 (avg)	1,327	\$ 48,280	88	1946	3,065	\$303,892	323
1944	13,319	552,977	848	1947	2,441	151,113	199
1945	2,446	285,520	274	1948	3,191	185,952	246

Utilization. An extraordinarily long list of uses has been developed for lithium, considering the small annual production. Its first noteworthy use was in the preparation of mineral waters, which were supposed to be beneficial in the treatment of arthritis and similar ills. It is used in the Edison-type storage battery. Lithium chloride is extremely hygroscopic and therefore useful if air-conditioned for the removal of humidity. Lithium compounds are employed in the manufacture of greases for use in extremes of heat and cold. Lithium has been incorporated in many alloys and was used in Germany in the development of bearing metals substituted for tin. Motock¹⁷ states that the addition of a few hundredth per cent lithium gave a degree of hardness to aluminum and its alloys not obtainable in any other way. A number of new compounds have been manufactured for commercial use, including the amide, hydride, peroxide, methyllate, carbide, nitride, and the borohydride. The peroxide has been used as a carrier of oxygen and the hydride as a carrier of hydrogen. During the war the hydride was used as a source of hydrogen for the inflation of small balloons and similar purposes.

Lepidolite and spodumene are used in limited tonnages in the ceramic industries. Lepidolite hardens and toughens glass and lowers the coefficient of expansion. Spodumene reduces shrinkage and lowers the firing temperature of white-ware. As summarized by Betz,¹ lithium exhibits the following properties in ceramic formulas: it is a powerful flux, particularly when used with feldspar; in glasses of low thermal expansion it permits the use of less alkali; it permits the manufacture of glasses of high electrical resistance and desirable working properties; a high lithia content aids in making glasses that transmit ultraviolet light; it has mineralizing effect; replacing lead monoxide by lithia reduces the tendency of a glaze to vaporize; maturing temperatures are lowered and the fluidity and gloss of enamels and glazes are increased.

Large crystals of lithium fluoride have been grown for use as a substitute for optical fluorite in the manufacture of lenses.

A mixture of spodumene and feldspar, which fuses at 6 or 7 pyrometric cones below the fusion point of pure feldspar, is marketed under the trade name of Lithospar.

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LITHOGRAPHIC STONE

Definition and Properties. Lithographic stone is a fine-grained, compact, homogeneous limestone that may be either pure calcium carbonate or dolomitic. It is usually gray, blue, drab, or yellowish in color and has an imperfect conchoidal fracture. It is used by lithographers in the form of rectangular slabs, on the surface of which designs are engraved. The surface of the engraved slab is inked and the design printed on paper. The common sizes of stones marketed range from 16 by 22 in. up to 43 by 64 in. and from 3 to 3½ in. in thickness.

According to Merrill:

A good stone must be sufficiently porous to absorb the greasy compound which holds the ink and soft enough to work readily under the engraver's tool, yet not too soft. It must be uniform in texture throughout and be free from all veins and inequalities of any kind, in order that the various reagents used may act upon all exposed parts alike. It is evident, therefore, that the suitability of this stone for practical purposes depends more upon its physical than its chemical qualities. An actual test of the material by a practical lithographer is the only test of real value for stones of this nature.*

Distribution. The best known deposits of lithographic limestone and those which supply most of the world's needs for high-grade stone are at Solenhofen and Pappenheim on the Danube in Bavaria, Germany. Here beds of limestone of Upper Jurassic age form a mass some 80 ft in thickness. Certain portions of these beds are suitable for lithographic purposes. The stone breaks out in slabs 3, 4, or 5 in. thick, which need only to be planed and polished. There are two grades of Bavarian stone, "yellow" or ordinary grade, and "gray" or "blue," which is of better grade and much more expensive. It is reported that the "blue" grade is produced only in two quarries.

Limestone, which has been found more or less suitable for lithographic purposes, has been located in many other parts of the world, but no other stone has been found equal in every way to the Bavarian stone. Deposits have been reported near Bath and Stony Stratford, England; Ireland; Department of Indre, France; Silesia; India; and in Harvey Township, Peterboro County, Ontario, Canada.

In the United States, deposits have been reported at various times in Arizona, Alabama, Arkansas, Indiana, Illinois, Iowa, Kentucky, Tennessee, Texas, Utah, and Virginia. The only deposit, however, that has yielded any important commercial production is near Brandenburg, Meade County, Ky. Here are found three distinct beds of limestone that may be used for lithographic stone, two about 3 ft thick and one 9 or 10 ft thick. In order to work these beds, considerable rock overburden must be removed, so that the good lithographic stone constitutes only about 20 per cent of the rock removed. No yellow stone was found. All the good stone was of a blue-gray color. Stones of the largest size were obtained, and in some respects this product compared favorably with the Bavar-

* MERRILL, G. P.: "The Non-metallic Minerals," 2d ed., p. 147, John Wiley & Sons, Inc., New York, 1910.

LITHOGRAPHIC STONE

ian stone. The quarries were worked more or less continuously from about 1900 to 1918.

Production and Consumption. No statistics are available to indicate world production or consumption. Production in the United States today is believed to be a matter of history. Changes in printing processes have rendered the true lithographic technology obsolete for common use. Photographic transfer to aluminum or zinc plates has been found faster and more economical. Such lithographic stone as is used today is employed in small amounts for special work.

Lithographic stone continues to have some small industrial significance since it is used in the manufacture of decalcomania, particularly those used in the decoration of chinaware. The stone is useful for this purpose because it holds considerable ink, which is transferred to the paper in substantial amount.^{3,4}

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MAGNESITE AND MAGNESIUM COMPOUNDS

The natural sources of magnesium and its compounds are many and varied; so also are the types of products made from these sources. The following list shows the principal natural sources of magnesium that are or have been used commercially:

Magnesite— MgCO_3

Hydromagnesite— $3\text{MgO} \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$

Dolomite*— $(\text{Ca}, \text{Mg})\text{CO}_3$

Brucite— $\text{Mg}(\text{OH})_2$

Olivine*— $(\text{Mg}, \text{Fe})_2\text{SiO}_4$

Forsterite*— Mg_2SiO_4

Serpentine*— $\text{H}_4\text{Mg}_3\text{SiO}_2\text{O}_9$

Epsomite— $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$

Kieserite— $\text{MgSO}_4 \cdot \text{H}_2\text{O}$

Bloedite (astrakanite)— $\text{MgSO}_4 \cdot \text{Na}_2\text{SO}_4 \cdot 4\text{H}_2\text{O}$

Sea water and residual bitterns (after removal of salt)

Natural brines and bitterns

Langbeinite*— $\text{K}_2\text{SO}_4 \cdot 2\text{MgSO}_4$

Carnallite*— $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$

Kainite*— $\text{KCl} \cdot \text{MgSO}_4 \cdot 3\text{H}_2\text{O}$

* These materials have been noted or covered briefly in other discussions.

All these materials at one time or another, depending on costs, availability, and markets, have been used to make one or more of the following products:

Refractory magnesia	Periclase
Calcined magnesia	Basic magnesium carbonate or "85% magnesia"
Caustic calcined magnesia	Magnesium chemicals, such as chloride, sulfate, and hydroxide
Dead-burned magnesite	Epsom salts
Dead-burned dolomite	Metallic magnesium
Precipitated magnesium carbonate	
Light calcined magnesia	

In addition we have the use of ground dolomite as a fertilizer and soil conditioner; its use in making dolomitic lime; and its many uses where its physical properties as a stone are utilized (dolomitic marble for example), rather than its chemical composition. Also we have the use of serpentine and olivine, calcined with phosphate rock to make a magnesium-rich phosphate fertilizer.

Langbeinite, carnallite, and kainite are used both as potash-magnesium fertilizers and as sources of magnesium chloride for making metallic magnesium.

TABLE 1. ANALYSES OF TYPICAL CRUDE AND CALCINED MAGNESITE

Source	Per cents						
	MgO	CaO	CO ₂	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	H ₂ O
1. Austria-Hungary, average crude.....	38-44	1-3	.....	2-7	2-7	1.5	
2. Austria-Hungary, average dead-burned...	85.57-90.0	0.96-3.52	.....	7.43-9.96	0-2.22	0.26-1.34	Mn ₂ O ₄ 0.51-0.76
3. Euboea, Greece, average crude.....	46.94	0.55	51.10	0.55	0.55	0.86	
4. Euboea, Greece, average caustic.....	91.00	2.50	.....	2.85	2.85	2.55	1.10
5. Euboea, Greece, average dead-burned....	90.62	4.10	.....	1.57	1.57	3.00	0.71
6. Finch Quarry, Northwest Magnesite Co., Wash., crude.....	42.48	2.45	.....	1.84	1.84	3.28	
7. Northwest Magnesite Co., dead-burned...	83.04	3.11	.....	7.02	7.02	6.78	
8. Red Marble Quarry, American Mining Production Co., Wash, crude.....	45.02	1.07	49.51	(FeO) 0.78	....	4.27	
9. Grenville district, Canada, crude.....	39.25	7.89	49.72	1.81	1.81	1.60	
10. Hydromagnesite, Atkin, British Columbia.	41.13	2.04	.....	1.42	....	1.86	18.02
11. Porterville, Calif., crude.....	45.17	1.32	50.74	0.26	0.03	2.28	
12. Red Slide, Sonoma County, Calif., crude..	43.42	0.04	48.08	0.29	0.26	7.67	
13. Salem district, India, crude.....	46.28	0.78	50.10	0.14	0.14	1.17	1.30

1. Analyses quoted by W. C. Phalen, The magnesite Industry in Austria, *Monthly Reports on Minerals Investigations*, U.S. Bur. Mines, August, 1919. (Natural ferromagnesite or brucenite.)

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6. Analysis by Northwest Magnesite Co., Chewelah, Wash.

7. Analysis by Northwest Magnesite Co., Chewelah, Wash.

8. Sample from stock pile. Analysis quoted in *Geol. Survey Wash., Bull. 25*, p. 15.

9. Dobbie mine, International Magnesite Co., Harrington Township, Grenville district, Quebec. Analysis by J. T. Donald and Company, Montreal. (Average analysis of shipment.)

10. Analysis from *Can. Geol. Survey, Mem. 98*.

11. *U.S. Geol. Survey, Bull. 355*, p. 56, 1908.

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MAGNESITE AND MAGNESIUM COMPOUNDS

Also combinations of two or more source materials may be used to make a single product or group of products; for example, sea water and dolomite, brucite and dolomite, magnesium chloride and dolomite, etc.

During the Second World War, metallic magnesium was made from magnesite, dolomite, brucite, sea water, natural brines, and langbeinite, and from combinations of these materials.

Thus, no simple, clean-cut picture of magnesium compounds can be presented.

MAGNESITE

Composition. Magnesite is magnesium carbonate MgCO_3 : MgO , 47.6 per cent; CO_2 , 52.4 per cent. Iron, magnesium, and calcium are often present. The analyses in Table 1 show the composition of typical magnesites mined commercially.

General Description. Magnesite is most commonly found in granular, compact, or earthy masses resembling unglazed porcelain; also in coarsely crystalline (or spathic variety) form resembling marble or coarse-grained dolomite in texture; more rarely in rhombohedral crystals or fibrous. *Breunnerite* is a term applied to the iron-bearing magnesite of Austria and elsewhere.

Physical Properties. *Hardness*, 3.5 to 4.5. *Specific gravity*, 2.9 to 3.1. *Melting point*, no true melting point. On heating to above 1700°C all the carbon dioxide is driven off. The resulting magnesia melts at about 2800°C , but softens far below this temperature. *Index of refraction*, 1.509 to 1.700. *Color*, white, yellow, brown, reddish, or nearly black. *Streak*, white. *Luster*, dull and earthy to vitreous. *Cleavage*, rhombohedral in crystals. *Fracture*, conchoidal in massive varieties. *Transparency*, opaque to translucent. *Tenacity*, brittle.

Occurrence. Magnesite deposits are of two general types: massive or compact and crystalline or spathic. Massive magnesite, the most common variety, is usually found in veins or masses in serpentine, resulting from the alteration of magnesia-rich rocks of the peridotite family. To this group belong the Grecian deposits, most of the California deposits, the deposits of the Bridge River district of British Columbia and many other deposits. The crystalline variety of magnesite is usually found as massive, bedded deposits associated with limestones and dolomites. Important deposits of this type are those of Austria; Stevens County, Wash.; and Grenville, Quebec, Canada.

The three general modes of origin of magnesite are (1) alteration of serpentine, resulting in such massive noncrystalline deposits as those of Greece; (2) sedimentary origin, such as the deposits of the Muddy River district near St. Thomas, Nev.; (3) replacement of calcareous sediments by magnesia-bearing solutions, forming deposits such as those of Austria-Hungary, Washington, and Quebec. Type 1 deposits in serpentine are usually in the form of large and small veins, lenses, and stockwork, and are erratic in distribution and extent. Type 2 deposits of sedimentary origin are more regular in occurrence, and reserves are more readily estimated. Type 3, or replacement deposits, are more regular than type 1 and less regular than type 2.

Before the Second World War Russia was by far the largest producer of mag-

nesite, with an average annual production for the 1934 to 1938 period of about 534,000 short tons. Austria averaged about 403,000 tons annually for the same period; Manchuria, 233,000 tons; the United States, 157,000 tons; Greece, 134,000 tons; and Czechoslovakia, 83,000 tons. Other fairly important producers were Yugoslavia, Canada, Australia (New South Wales), Korea, Germany (Prussia), and India.

During the war the production of all types of magnesium compounds was greatly stimulated, due in part to the very large demand for refractories for the metallurgical industries and in part to the tremendous development of the metallic magnesium industry. These demands not only caused large expansions in the going operations but also led to the emergency development of many new deposits of magnesite and of new sources such as sea water, brucite, and langbeinite. The war peak for magnesite production alone, reached in 1943, was over 750,000 tons of crude magnesite, or nearly 5 times the prewar average. Postwar years have seen the production shrink back again to peacetime requirements, but in 1946 it was still nearly twice the 1937-1939 average.

United States. Only three states are or have been important producers of magnesite: Washington, California, and Nevada. Small deposits, some of which have been worked to a limited extent, occur in Texas, New Mexico, and Utah. Until 1916, when the large deposits in Stevens County, Wash., were discovered, California was the only producing state and the industry was pioneered there. During the Second World War, when the extensive magnesite-brucite deposits of the Luning area in Nevada were developed on a large scale, that state became a very important producer, chiefly for metallic aluminum. Since the war these operations have been greatly curtailed and Washington has again become the largest producer.

Washington. Very large deposits of coarsely crystalline magnesite occur in Stevens County, Wash., centering about Chewelah and Valley, 60 miles north of Spokane. Most of the magnesite is colored, varying from white through pink, red, and gray to black. It occurs as replacements of large lenses of dolomite in sedimentary beds. The larger deposits are 200 or more ft thick and 1,000 or more ft long, dipping at angles of up to 45 deg. Estimates of reserves of 1 million tons each within 100 ft of the surface are reasonable for at least three of the deposits. It is considered of better grade for refractory purposes than the California material, while the latter is preferred for caustic magnesite for structural purposes. It contains very little iron, and for refractory uses iron must be added before calcining. The rock as mined averages high in lime (from dolomite inclusions) and in silica, but the quality is greatly improved by beneficiation.

California. This state has probably passed its peak as a magnesite producer and some of the once important districts, such as Porterville, are now only of historic interest. Magnesite, almost wholly of the "amorphous" or cryptocrystalline variety, occurs in many deposits, usually of the irregular-vein, lens, or stockwork type, throughout the Coast Range and on the west slope of the Sierras from Mendocino and Placer counties on the north to Riverside County on the south. At the peak of California production in 1917 operations were active in 13 counties. Deposits tend to be small, though of high grade. In 1946 production

MAGNESITE AND MAGNESIUM COMPOUNDS

was reported only from the Western mine near Livermore, but the famous Bald Eagle mine near Gustine was operated as late as 1944.¹⁷

Nevada. Very extensive deposits of high-grade crystalline magnesite and brucite occur in the Luning district on the northwestern slope of the Paradise Range in northwestern Nye County, Nev., about 200 miles south of Reno. These deposits, now generally known as the Gabbs or Gabbs Valley deposits, have been described in detail by Callaghan.² During the Second World War there were several important operations here, the largest being the mining, flotation, and calcining plant to process 2,000 tons per day for the basic magnesium metal plant near Las Vegas. In 1946 relatively small-scale production continued here, chiefly for "caustic-calcined" uses.

A very large bedded deposit of massive, fine-grained, white magnesite, rather high in silica and lime, occurs in the valley of the Muddy River, near St. Thomas, Clark County, and other deposits of high-grade magnesite are known in eastern Nevada.

Other States. Caustic calcined magnesite for the fertilizer market is made at Llano, Texas, from low-grade deposits nearby. A very small production has come from Juab County, Utah, and deposits of possible commercial interest exist in Grant County, New Mexico.

Russia. As the world's largest prewar producer of magnesite Russia has extensive deposits of high-grade crystalline magnesite. The most important are 7½ km northeast of Satka in the western Ural Mountain district. Other large deposits are reported near Lake Baikal, East Siberia. In addition to supplying her own needs Russia exported large tonnages to England, France, Germany, and other countries.

*Austria and Czechoslovakia.*²⁴ Prior to the First World War the best known magnesite deposits in the world and the ones which then furnished most of the world's supply were those of Austria-Hungary, now belonging in part to Austria and in part to Czechoslovakia. These deposits are a series of lenses in dolomite in a narrow belt with a general northeasterly trend, extending across these countries for several hundred miles. The most important are at Veitsch in Styria and at Radenthein. The ore is of the crystalline type, containing 2 to 5 per cent iron oxide, 1 to 5 per cent silica, and 1 to 3 per cent lime.

Manchuria. Among the world's largest magnesite deposits are those of Manchuria along the line of the Manchurian Railroad between Mukden and Dairen. One group of deposits on the east side of Ta-shih-chiao covers an area 50 km long by 6 km wide and is reported to contain 5 billion tons. Exports of dead-burned and caustic magnesite were made to Japan, Europe, and the United States.

Greece. Deposits of magnesite are known in several localities in Greece, but by far the most important are those on the island of Euboea. The magnesite is amorphous, closely resembling both physically and chemically that from California. It occurs with serpentine as veins, masses, and stockworks. The most important deposits are those of Mantoudi, Daphnopotamous, Limni, Pyli, Afrati, and Hajia Anna, all easily accessible to the coast. The largest deposit is at Mantoudi on the northeast coast. This deposit is 1,800 ft long and has a

maximum width of 130 ft and a dip of 35 deg. It has been mined to a depth of over 300 ft, with little indication of decrease in size. The product is all exported either in crude form or as calcined to the caustic state (most important before the war) or to the dead-burned state.

Canada. Quebec. The most important magnesite deposits in Canada are in the Grenville district, Argenteuil County, Quebec, about halfway between Ottawa and Montreal. The four principal localities are about 12 miles north of Grenville. The magnesite occurs, closely associated with dolomite, in lenticular masses, intensely faulted and folded, with bands or lenses of serpentine in metamorphosed sediments consisting of crystalline limestone, garnet gneiss, and quartzite. It is crystalline and cream white, milk white, or gray in color. Outcrops are as much as 1,000 ft long and 300 ft wide. While these deposits are of moderate size and high in lime, due to included dolomite, they have been of some importance because of their location. Since the discovery of the brucite deposits of Quebec and Ontario and their successful commercial development (see Brucite) these magnesite deposits have become of less interest.

Korea. Very large deposits of magnesite have been reported in Korea—one of 3 billion tons in Tansengun, South Kankyo Province. Other deposits have been worked near Gosui, North Kankyo Province, largely for export to Japan.

Other Countries. Deposits of known or probable commercial importance occur in *Italy* (near Livorno); in *New South Wales* (at Attunga and Piedmont); in *Western Australia* (near Port Pirie and Robertstown); in *India* (Madras); in *Mexico* (Santa Margarita Island, Lower California); in *Spain* (Province of Santardes); *Sweden* (near Narbotten in Kvickjock parish, and in Paturkorso Valley between Suliteluna and the North Sea); in *Russia* (near Ufa in Orenburg, and in the Kuban district of the Caucasus); in *South Africa* (in the Barberton district of eastern Transvaal, between Kaapmuiden and Malelane); in *Portuguese West Africa* (large deposits in North Bihe district, 200 miles east of Benguela); in *Turkey* (Eskisehir province, 75 km from Smyrna); in *New Caledonia* (large deposits on west coast); in *Silesia* (at Baumgarten and Grochan, south of Frankenstein); in *Venezuela* (Margarita Island); in *Macedonia* (near Salonika, Greece); in *Norway* (at Snarum and near Dammen).

Sources of Magnesium Compounds. *Hydromagnesite* is a natural basic magnesium carbonate, $3\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$; MgO, 43.9 per cent, CO_2 , 36.3 per cent; H_2O , 19.8 per cent. In chemical composition this is close to artificially precipitated basic magnesium carbonate (see Dolomite).

Hydromagnesite is a soft, white mineral found in small tufted crystals, but more usually in chalklike masses somewhat resembling amorphous magnesite. It may occur as an alteration product of serpentine, but more commonly is derived from dolomite. It is found commercially associated with dolomite and/or magnesite and sometimes brucite.

Fairly large deposits of hydromagnesite occur in British Columbia in the Atlin, Williams Lake, and Clinton districts. At one time a deposit at Tatton was worked and the product shipped to Vancouver for making plastic magnesia.

In Spain hydromagnesite has been mined in the Reinosa district of the province of Santander, but it is of low grade due to contamination with dolomite.

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Sea Water as a Source of Magnesium Compounds. As shown in Table 2 by Chesney,³ next to sodium, magnesium is the most abundant solid constituent of sea water.

TABLE 2. COMPOSITION OF SEA WATER

<i>Grams per Liter of Sp Gr 1.024</i>	
NaCl.....	27.319
MgCl ₂	4.176
MgSO ₄	1.668
MgBr ₂	0.076
CaSO ₄	1.268
Ca(HCO ₃) ₂	0.178
K ₂ SO ₄	0.869
B ₂ O ₃	0.029
SiO ₂	0.008
Iron and alumina, R ₂ O ₃	0.022

This source may be used directly or by treating the residual bitterns after the removal of common salt and sometimes bromine. Recovery processes depend upon the almost complete insolubility of magnesium hydroxide in water. The raw sea water or bitterns are treated with high-calcium lime or dolomitic lime, precipitating the magnesium as the hydroxide. When dolomitic lime is used its magnesium content is added to that from the sea water, thus greatly increasing the recovery. The resultant product, after washing, thickening, and filtering, is used to make caustic or refractory magnesia or magnesium chemicals or, ultimately, metallic magnesium. Magnesia from sea-water plants are operated as follows: from residual bitterns, Newark and South San Francisco, Calif.; from sea water, Moss Landing, Calif.; Velasco and Freeport, Tex.; and Cape May, N.J.

Well brines are at present the most important sources of magnesium chloride and sulfates in the United States. The Dow Chemical Co. pioneered the manufacture of metallic magnesium from magnesium chloride obtained as a by-product from the natural well brines at Midland, Mich., used primarily as a source of sodium chloride for making sodium compounds and chlorine. During the Second World War there were developed other sources of magnesium chloride, such as langbeinite from Carlsbad, N.Mex., and sea water, but the Michigan brines continue to be very important sources not only of the chloride but also of the sulphate, the hydroxide, and even the oxide. Plants are or have been operated at Midland, St. Louis, Manistee, and Ludington, Mich. A deposit of natural brine, high in magnesium chloride, is reported near Gail, Border County, Tex.

In 1941 and 1942 a large deposit of carnallite (KCl·MgCl₂·6H₂O) and sylvite (KCl) was explored by the U.S. Bureau of Mines by drilling, near Thompsons, 30 miles north of Moab, Grand County, Utah. Here at a depth of about 3,500 ft is a rich zone of these salts about 220 ft thick. Brines from these holes, nearly 30 per cent solids, consist of approximately 52 per cent MgCl₂, 27 per cent CaCl₂, 13 per cent KCl, 8 per cent NaCl, and 0.15 to 0.20 per cent bromine. It was proposed to erect a plant here to produce 500 tons per day of anhydrous magnesium chloride, but the project was not started.

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The magnesium sulfate brine well operation at O'Donnell, Tex., has been noted under Epsomite.

Production and Consumption. The essential features of production and consumption of magnesite and the primary products made from it are shown in Tables 3 and 4.

TABLE 3. SALIENT STATISTICS OF THE MAGNESITE INDUSTRY IN THE UNITED STATES, 1942 TO 1946

	1942	1943	1944	1945	1946
Crude magnesite:					
Mined:					
Short tons.....	497,368 ^a	754,832	561,450	336,458	324,640
Value.....	\$3,874,334	\$6,071,596	\$4,407,461	\$2,324,957	\$2,225,850
Sold by producers:					
Short tons.....	6,835	4,090	b	b	b
Value.....	\$57,350	\$47,788	b	b	b
Average per ton ^c	\$8.39	\$11.68	b	b	b
Imports for consumption:					
Short tons.....	.....	.....	1,039	.....	1
Value.....	.....	.....	\$34,588	.....	\$56
Caustic-calcined magnesia:					
Sold or used by producers:^d					
Short tons.....	41,889	191,792	139,243	43,270	45,178
Value.....	\$2,028,126	\$11,497,505	\$6,481,963	\$2,503,544	\$2,854,538
Average per ton ^c	\$48.42	\$59.95	\$46.55	\$57.86	\$63.18
Imports for consumption:					
Short tons.....	578	290	559	445	441
Value.....	\$19,105	\$13,122	\$15,286	\$12,134	\$12,985
Refractory magnesia:					
Sold or used by producers:^e					
Short tons.....	273,661	301,382	278,490	254,994	244,824
Value.....	\$7,823,963	\$9,341,183	\$8,426,049	\$7,414,218	\$7,231,869
Average per ton ^c	\$28.59	\$30.99	\$30.26	\$29.08	\$29.54
Imports for consumption:					
Short tons.....	7,728	9,233	6,176	5,506	1,873
Value.....	\$280,342	\$310,497	\$260,062	\$234,519	\$182,574

^a Partly estimated; most of the crude is processed by the mining companies, and very little enters open market.

^b Bureau of Mines not at liberty to publish figures.

^c Average receipts fob mine shipping point.

^d Includes caustic-calcined magnesite and reactive magnesia from sea-water bitters, well brines, and raw sea water and from precipitated magnesium carbonate obtained from dolomite.

^e Includes dead-burned magnesite and refractory magnesia from brucite, dolomite, sea-water bitters, well brines, and raw sea water; there was none from well brines in 1944.

World production since the start of the Second World War has been so incomplete and fragmentary as to be meaningless. The general prewar picture has already been given (pages 298 to 299). Since the war, production in Europe, Manchuria, Korea, and other war-area countries has recovered, but very slowly, or has been dormant. On the other hand, a few countries that had little or no prewar production, such as Australia, Brazil, and Sweden, have reported fairly important production chiefly for their own needs.

Although world demands for magnesite and magnesium compounds have greatly increased, due to the development of the metallic magnesium industry, to

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new uses in fertilizers, to expanded needs for refractories in the metallurgical industries, and to new uses, the known reserves of commercially exploitable deposits have more than kept pace. This has been due to the discovery of new magnesite deposits, to the application of flotation to low-grade ores, to the development of new methods for extracting magnesia from dolomite, and to the development of new sources such as brucite, hydromagnesite, and sea water. It is impossible to visualize how there can ever be any real scarcity of magnesium mineral resources.

TABLE 4. MAGNESIA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 AND 1948, BY KINDS AND SOURCES

Magnesia	From magnesite, brucite, and dolomite		From well brines, raw sea water, and sea-water bitterns		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1945						
Caustic-calcined.....	16,098	\$1,122,119	27,172	\$1,381,425	43,270	\$ 2,503,544
Refractory.....	193,693	5,068,987	61,301	2,345,231	254,994	7,414,218
	209,791	\$6,191,106	88,473	\$3,726,656	298,264	\$ 9,917,762
1948						
Caustic-calcined.....	11,548	\$ 996,713	21,661	\$2,383,815	33,209	\$ 3,380,528
Refractory.....	214,628	7,954,089	115,441	5,490,498	330,069	13,444,587
	226,176	\$8,950,802	137,102	\$7,874,313	363,278	\$16,825,115

Mining and Preparation. Methods of mining and preparing magnesite vary considerably in the several important consuming districts, depending not only upon the nature of the magnesite, but also upon the purposes for which it is to be used. Magnesite may be shipped in either the crude or the calcined form. The calcined product may be either "dead-burned" (a product from which practically all the carbon dioxide has been driven off, used as a refractory) or burned to "caustic" magnesite (a product in which 3 to 8 per cent carbon dioxide is left in the residue, used in making oxychloride or Sorel cement). If the crude magnesite is to be dead-burned, it should contain sufficient iron oxide to make the product bond or set well in furnace bottoms or in brick. Some of the natural magnesite contains sufficient iron oxide for this purpose (the Austrian product is the best example) and in other cases iron oxide must be added before calcining (for example, the Washington magnesite). From 4.5 to 8.0 per cent iron oxide in the dead-burned product is considered the most desirable content. The methods of mining and preparation used in the most important districts are discussed below.

Mining Methods. In Austria-Hungary and Czechoslovakia most of the magnesite is obtained by open quarrying in benches, followed by sorting and hand cobbing. In Stevens County, Wash., open quarrying is most common, but glory-hole mining is also used. In California most of the ore is removed by under-

ground mining, but glory holes and other methods are sometimes used. In Greece the upper parts of the magnesite bodies are worked by open quarrying, but some of the deposits have been worked from shafts several hundred feet deep. The Canadian deposits have been worked chiefly by open quarrying. Careful sorting and cobbing are necessary.

Beneficiation. In some magnesites, like most of those in California, the impurities are generally softer than the pure magnesite and thus, in grinding, migrate to the fines. This property has been used to effect a rough separation of magnesite from impurities, mainly siliceous, although alumina and iron generally follow the silica. By graded, crushing, and screening, the coarser products may be made very low in silica, and the fines, high in silica, may be used for low-grade purposes or wasted.

During the period from 1936 to 1939 the U.S. Bureau of Mines developed methods of purifying magnesite ores by froth flotation,⁵ and in 1941 the Northwest Magnesite Co. completed a 300 ton per day flotation plant at its Chewelah, Wash., operations. This process was successful, and later sink and float concentration was added to treat coarser sizes. As noted under Talc, flotation has been used to separate the bruennerite variety of magnesite from Vermont talc.

Calcining Methods. Used in the early development of the industry in this country (and still used in some foreign countries) were two types of vertical kilns: small bottle-shaped kilns and kilns resembling vertical lime kilns. These handled only lump ore and were used, in this country, chiefly for making caustic grade. Where iron oxide or other agents had to be added to make refractory grades the rotary kiln was essential, and gradually this type of kiln was adopted for making all types of products.

The object of calcination is to make either (1) caustic magnesite, for plastic magnesite cement, containing 3 to 8 per cent carbon dioxide, or (2) dead-burned magnesite, for refractories, containing only about $\frac{1}{2}$ per cent carbon dioxide. Caustic magnesite is usually sold in a finely pulverized form. Dead-burned magnesite is sold either (1) as dead-burned grain, which consists of granules and nodules up to $\frac{5}{8}$ or $\frac{3}{4}$ in. in diameter, or (2) as lump, which is later ground and used for the making of magnesite brick. Dead-burned magnesite must contain sufficient impurities (perhaps 8 to 14 per cent), such as iron, silica, and lime (chiefly iron), so that it will bond under heat. Some crude magnesites naturally contain sufficient iron and so on for this purpose, for example, the Austrian product and some of the Californian magnesite. Such iron-bearing magnesites are sometimes called natural *ferromagnesites*. They are not so suitable for making caustic magnesite, but are particularly adapted for refractory purposes. When noniron-bearing ore is to be used for making the dead-burned product, iron usually must be added, commonly in the form of iron ore. Magnesite to be calcined to the caustic state and ferromagnesite for the dead-burned product may be calcined in any of the three types of kiln noted above, but, when iron ore must be added, calcination is carried on only in rotary kilns.

Caustic magnesite is made by calcining to a temperature of 700 to 1000°C. Dead-burned magnesite is calcined at 1450 to 1500°C if high in iron, but 1600 to 1700° is required if the ore is low in iron or other impurities. In calcining to the

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dead-burned state, not only is nearly all the carbon dioxide driven off, but also the particles sinter, shrink, and become hard, dense, and inert. The dead-burned product usually varies in color from reddish through chocolate brown to black. Pure magnesite is sometimes calcined in the electric furnace above 1700°C to a hard, flinty mass. This product, known as electrically shrunk or fused magnesia (artificial periclase), has a specific gravity of about 3.65 and shows no additional shrinkage on further heating.

Austrian magnesite is calcined in both vertical and rotary kilns. The sintered product is quenched with water, crushed, screened, sorted, passed over magnetic separators, crushed a second time, resorted, recrushed to $\frac{1}{4}$ in., and sacked for shipment. The Grecian ore, used chiefly to make caustic magnesite, is burned in bottle-shaped, vertical kilns, followed by hand-sorting. Part of the Canadian magnesite has been calcined to the caustic state in vertical kilns, but most of it has been burned in rotary kilns to the dead-burned state by methods similar to those used in Washington, described below.

Nearly all the California magnesite is of the compact or amorphous type. Part of it is low in iron and part is natural ferromagnesite. The chief product before the war was caustic magnesite, but during the war considerable dead-burned product was made both from natural ferromagnesite and from low-iron magnesite plus iron ore. In a few cases a low-iron magnesite has been calcined in vertical kilns, crushed, mixed with iron ore, and recalcined in rotary kilns.

Refractory-grade calcined magnesite is of two types: (1) brick grade, containing 83 to 90 per cent magnesia, and (2) maintenance grade, containing 60 to 82 per cent magnesia, used principally to build up and patch the bottoms and sides of open-hearth steel furnaces. Analyses of typical products are given in Table 5.

TABLE 5. ANALYSES OF CALCINED MAGNESITE

	1	2	3	4	5	6
MgO.....	84.97	97.2	93.5	82.3	92.2	94.0
CaO.....	3.10	1.5	1.4	4.7	1.8	1.9
Fe ₂ O ₃	7.96	0.2	0.2	6.5	0.3	0.3
Al ₂ O ₃	7.96	0.3	0.3	1.5	0.4	0.3
SiO ₂	2.91	0.6	0.6	5.0	5.3	1.9
Mn ₂ O ₃	0.68					
Ignition loss.....	0.38	0.2	4.0	....	....	1.6

1. Austrian dead-burned magnesite, U.S. Tariff Comm., "The Magnesite Industry," 1920, p. 14.

2. Chemical magnesia, Newark, Calif., sea water; Max Y. Seaton, Production and Properties of the Commercial Magnesias, *Am. Inst. Mining Met. Engrs., Tech. Pub.* 1496, July, 1942.

3. Caustic magnesia, Newark, Calif., sea water; Seaton, *op. cit.*

4. Maintenance, dead-burn, Newark, Calif., sea water; Seaton, *op. cit.*

5. Periclase, Newark, Calif., sea water; Seaton, *op. cit.*

6. Caustic grade, Bald Eagle Standard, Gustine, Calif.; Seaton, *op. cit.*

Marketing and Shipping. Crude magnesite is shipped in either open-top or boxcars, although little is sold in this form. Caustic or plastic calcined magnesite

may be shipped in lump form in boxcars to grinding plants in the central and eastern states, or shipped in ground form in paper or paper-lined cloth bags holding 150 lb each. Dead-burned lump magnesite is shipped in bulk in boxcars. Dead-burned grain is preferably shipped in 200-lb cloth bags, but may be shipped in bulk in boxcars.

The markets for dead-burned magnesite products are in the large steel-producing centers of the East, but caustic magnesite for cement, stucco, and flooring is used all over the country. However, magnesite cement flooring and stucco has been probably more popular on the Pacific coast and in the midwestern cities than in the East.

Caustic magnesite deteriorates on contact with moist air and must be carefully stored.

Prices. In 1950 dead-burned grain magnesite was quoted at \$33 per ton, carload lots, bulk, fob Washington state. Caustic calcined, 85 per cent magnesia, oxychloride grade, was quoted at \$70 per ton fob California; sea-water granular, \$57 per ton; sea-water periclase, 90 per cent grade, \$50.50 per ton; and sea-water periclase, 93 per cent grade, \$75 per ton. Magnesium metal, ingot, carload lots, was quoted at 20.5 cents per pound.

Specifications and Tests. Because of the somewhat confusing and interchangeable use of terms designating magnesite and its products, McDowell and Howe have defined these terms as ordinarily used. Their definitions are as follows:

Magnesite. (1) The mineral MgCO_3 , the crude material of the magnesite industry; (2) a term applied to various products manufactured from the mineral MgCO_3 , such as "dead-burned" and "plastic" magnesite, magnesite brick, and so forth.

Plastic Magnesite or Caustic-burned Magnesia. The product which results from calcining crude magnesite at a comparatively low temperature and which contains about 2 to 5 per cent CO_2 ; called also calcined magnesite.

Calcined Magnesite. (1) Magnesite that has been calcined at any temperature, including both caustic- and dead-burned; (2) an intermediate product between caustic- and dead-burned magnesite, *i.e.*, magnesite which has been calcined but not sintered, and in which the CO_2 content is below 2 per cent, usually about 1 per cent.

Dead-burned Magnesite or Dead-burned Magnesia. A sintered product obtained by calcining magnesite at a high temperature; it usually contains less than 0.5 per cent CO_2 and almost invariably contains 4.5 to 8 per cent Fe_2O_3 , either naturally or by additions of iron ore during the treatment.

Electrically Shrunk Magnesia. Magnesite calcined in the electric furnace to effect complete shrinkage; usually of a high degree of purity.

Magnesia or Magnesite Brick. Brick consisting essentially of MgO , generally containing 4.5 to 8 per cent Fe_2O_3 . It has been suggested that brick with this amount of iron be called "magnesite brick," and those nearly free from iron "magnesia brick," but the latter term is more frequently applied to both.

Magnesia. (1) The pure oxide of magnesium; (2) a term applied synonymously with "magnesite" to brick, dead-burned material, and so forth; (3) to certain magnesite products low in impurities and high in MgO , as magnesia crucibles, electrically shrunk or fused magnesia, and so forth; and (4) also applied to precipitated or basic carbonate of magnesia.

Basic Carbonate of Magnesia. A light, powdery material prepared either by boiling a solution of acid magnesium carbonate or by double decomposition of a soluble

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magnesium salt and a soluble carbonate. The composition of the commercial product varies somewhat, but is generally given as $3\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 + 3\text{H}_2\text{O}$, the same as that of hydromagnesite.¹³

Little magnesite is sold to the ultimate consumer in the crude state, except to the manufacturers of epsom salts and other chemicals. For this purpose pure magnesite in 4- to 14-in. lumps is required. Today even the latter users generally prefer chemical calcined or caustic grade to crude magnesite.

The requirements for all grades of calcined magnesite are very rigid and exacting. The value of caustic magnesite cannot be determined by chemical analysis alone, since its color, setting qualities, plasticity, and other physical properties demanded by use requirements cannot be predicted from chemical composition. This was found to be true when magnesite products made from sea water were first substituted for products made from natural magnesite.

Caustic and chemical grades of calcined magnesite are usually ground to about 95 per cent through a 200-mesh screen.

Utilization. Except for the war use of magnesite for making metallic magnesium at Las Vegas, Nev., terminated after the war, by far the largest use for magnesite is for refractories.

Dead-burned magnesite is a basic refractory and, as such, forms the principal refractory used in basic open-hearth steel furnaces and basic converters. It is also used in electric furnaces, in other types of furnaces and converters, in kilns for pyrite burning for sulfuric acid manufacture and in portland-cement and other types of kilns. Use in basic open-hearth steel furnaces is by far the most important on the basis of quantity used. In the form of dead-burned grain it is used in making the hearth, in fettling, and in patching. In the form of brick it is used to line the walls, ends, ports, and crowns.

In addition to pure magnesite brick other basic to neutral refractories are made from mixtures of magnesite with chromite, silica, and other refractory materials. In the refractory field magnesite must also compete with other magnesia refractories, which include dead-burned dolomite, dead-burned mixtures of dolomite and magnesite (as at Kilmar, Quebec), dead-burned mixtures of dolomite and brucite (as at Mapleton, Ohio), and olivine-forsterite refractories.

In the past 20 years the amount of all types of high-magnesia refractories made from magnesite, dolomite, and brucite used in the United States in basic open-hearth and electric steel production has ranged from 3 to 7.6 lb per ton of steel. The normal peacetime average is about 4.8 lb per ton of steel.

Oxychloride or Sorel Cement. If finely ground caustic magnesite is mixed with a solution of magnesium chloride, a plastic cement is formed that will set to a hard, dense, tough, elastic product which can be drilled, planed, scraped, and burnished like wood. The composition of the product is believed to correspond to the formula $\text{MgCl}_2 \cdot 5\text{MgO} \cdot 10\text{H}_2\text{O}$. Nearly any strength of magnesium chloride solution will produce a setting action, but a solution of 20 to 22°Bé gravity is ordinarily used. The mixture is usually modified for various uses by the addition of coloring matter and such filler materials as wood fiber, cork, talc, silica, asbestos, marble dust, and sand.

During the 1920's this product was popular for exterior stucco and for floors

and walls in residential construction, but its use gradually declined because it was not fully weatherproof and because it was more expensive than competitive materials. Because of its toughness, durability, flexibility, and resistance to heat, however, its use has continued as a flooring material in pullman and other railroad cars, hospitals, railway stations, schools, offices, kitchens, ship decks, and other public and semipublic places. Much research has been done to improve and stabilize the product, and it has been frequently predicted that its use will again increase.

Other Uses. It has been recognized in recent years that many soils are deficient in magnesium, and there is a large and growing demand for fertilizers containing that element. This is being supplied by a wide variety of materials, including dolomite, crude and calcined magnesite, calcined mixtures of olivine or serpentine and phosphate rock, and potash-magnesium salts such as langbeinite, carnallite, and kainite.

Light-calcined (caustic) magnesia, finely pulverized, is used in rubber, where it acts mainly as an accelerator.

Basic magnesium carbonate and epsomite are both sometimes made from magnesite, but more commonly they are derived from other sources (see Dolomite and Epsomite).

Activated magnesia for use as a decolorizing, neutralizing, and adsorbing agent is made in one process by heating precipitated magnesium hydroxide until 80 to 85 per cent has been converted to the oxide. A typical analysis shows MgO , 70.84 per cent; $\text{Mg}(\text{OH})_2$, 14.38 per cent; MgCO_3 , 8.78 per cent; MgSO_4 , 1.36 per cent; CaCO_3 , 3.42 per cent; with a minor content of SiO_2 , NaCl , Fe_2O_3 , and Al_2O_3 . It is reported that the dry powder has 5 to 10 times the decolorizing power of bentonite or fuller's earth (British Patent 483,096, Apr. 12, 1938).

A synthetic, hydrous magnesium silicate called magnesol is a highly adsorptive agent used in dry cleaning, in oil refining, and in other industries as an industrial adsorbent.

For many years the principal use for California magnesite was in making sulfite paper pulp on the Pacific coast. Magnesium bisulfite is said to be superior to calcium bisulfite because it is more stable, because it dissolves more completely the noncellulose matter (free resins), and because the residues left in the paper stock are not injurious to the sizing agents subsequently used.

Mixtures of calcined magnesite and alumina have been fused together in an electric furnace to make a high-grade refractory product of the composition of the mineral spinel.

Magnesium chloride may be recovered directly from well brines, as at Midland, Mich.; from kainite or carnallite as in Germany; from langbeinite¹² by treating with sylvite (KCl) as at Carlsbad, N.Mex., from sea water and bitterns; or by the direct reaction of hydrochloric acid on magnesite, magnesium oxide, or hydroxide. Its largest use is in making metallic magnesium.

Magnesium hydroxide or milk of magnesia, may be made direct from sea water¹¹ as at South San Francisco, Calif., or from magnesite, calcined magnesite, or magnesium chloride or sulfate.

Magnesium sulfate is treated in the section on Epsomite.

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MEERSCHAUM—SEPIOLITE

Composition. Meerschaum or sepiolite is hydrous magnesium silicate, $H_4Mg_2Si_3O_{10}$: SiO_2 , 60.8 per cent; MgO , 27.1 per cent; H_2O , 12.1 per cent.

General Description. Meerschaum occurs only in compact, finely granular, nodular, soft, earthy or clayey masses, white, and very lightweight when pure. The name "meerschaum" (German for "sea foam") arises from the fact that when pure and dry it will float on water. It is highly absorbent, and when wet it is soft and somewhat plastic. When dried again, it becomes hard and tough. Some forms have a fibrous or leathery texture and in these the toughness is very pronounced.

Physical Properties. *Hardness*, 2 to 2.5. *Specific gravity*, 1 to 2. *Index of refraction*, 1.519 to 1.529. *Color*, white, yellowish, or grayish. *Streak*, white. *Luster*, dull. *Cleavage*, none. *Fracture*, conchoidal to uneven. *Transparency*, opaque. *Tenacity*, tough.

Occurrence. Meerschaum usually occurs as an alteration product of magnesite, serpentine, or possibly impure opal high in magnesium. It is generally found in nodular masses in serpentine or in secondary deposits.

Foreign Countries. The most important deposits of meerschaum are in *Anatolia, Asia Minor*, near the town of Eskishehr (the ancient Dorylaeum) in the eastern part of the vilayet of Brusa. Eskishehr is on the River Brusa at the junction of the Angora and Konia Railway lines, about 120 miles southeast of Constantinople. Here meerschaum mining was started over 2,000 years ago by the early Greeks, who used the product for purposes now unknown. Around the town of Eskishehr is a high plateau surrounded on all sides but the east by mountains. At the foot of the mountains are the meerschaum deposits, principally about 20 miles east of the town. The mineral is found as nodules in alluvial deposits, probably of lacustrine origin. The nodules vary in size from that of an egg to that of a football. They occur mixed with fragments of serpentine and other magnesian and hornblende rocks.

Meerschaum deposits have also been reported on the islands of Euboea and Samos in *Greece*; near Hrubshitz in Moravia, *Czechoslovakia*; in *Bosnia*; in *Morocco*; and near Vallecas, Madrid, and Toledo in *Spain*. A mineral known as *aphrodite* found near Langbanshyttan in *Vermland, Sweden*, is closely allied to meerschaum.

United States. Meerschaum is found in *New Mexico* at two localities in Grant County in the upper Gila River Valley. One deposit is in the Alunogen mining

district on the headwaters of Sapillo Creek about 23 miles by airline north of Silver City. The other is in the Juniper mining district in Bear Creek Canyon, about 12 miles northwest of Silver City. At the latter locality the meerschaum occurs in veins, lenses, seams, and balls, mostly in fractures in a limestone, together with chert, quartz, calcite, and clay. It is believed that about 1,000 tons was produced before 1914.

Meerschaum has also been noted in small quantities near Concord and Middletown, Delaware County, and near West Nottingham, Chester County, *Pennsylvania*; at the Cheever Iron Mine, Richmond, *Massachusetts*; and New Rochelle, Westchester County, *New York*.

Production. Production in Turkey has declined, in part due to the use of competitive materials. Before the war meerschaum was one of the principal exports of Turkey. Production of 9,520 kilos was reported in 1944. It is expected that some increase in output will be recorded.

Mining and Preparation. In the Eskishehr district, Penzer⁴ states that mining methods are very primitive. Permits to mine anywhere may be obtained for 5 Turkish lire. Miners work either on their own account or for contractors, at wages of about 1½ lire per month. Shafts, about 3 ft square, are started in the upper clay stratum, using only axes and shovels as tools, and are sunk to a maximum depth of from 60 to 100 ft. As meerschaum nodules are found, mixed with fragments of serpentine and other rock, they are removed by a system of drifts and crosscuts. The ore is hoisted in baskets by a wooden hand winch. Horizontal workings are untimbered, and practically no pumping is done. Workings are subject to frequent floods and cave-ins.

At the surface the ore is packed in bags, sold to minor traders, and hauled in carts to Eskishehr. Here it is sold to wholesalers or to depots maintained by Viennese firms.

Since no raw meerschaum is allowed to be exported by the Turkish government, it is prepared in a preliminary way before shipment.

The crude material as received from the mines is stored in damp cellars and allowed to become thoroughly moistened, for it hardens on drying so that it is very difficult to clean. It is then cleaned of adhering dirt, the bad places cut out, and the surfaces rounded. Next it is dried, in summer in the open air, but in winter in special drying chambers. Artificial drying requires about a week and the process must be carried on very slowly and carefully so that no cracking or staining by smoke will result. In drying, meerschaum loses about two-thirds of its weight and becomes harder and snowy white in color. However, reddish or yellowish material cannot be made pure white. The lumps are then smoothed with horsetail grass, polished with a flannel dipped in warm water, waxed, graded, and packed for shipment.

Thirteen grades of meerschaum are recognized, and each is sorted into four major and four minor sizes. These sizes are determined by the number of pieces that can be packed into standard boxes. For the three larger sizes, boxes 6¾ by 12½ by 28 in. are used; for the other sizes, boxes 7½ by 14¾ by 32 in. Each piece is wrapped in cotton and the box is built around the pieces, so that when the packing is finished no piece can be withdrawn and replaced.

The boxes are shipped over the Anatolia Railroad to Constantinople, thence to Vienna by way of Trieste or to other large markets.

Utilization. The use of meerschaum for pipe making first started in Budapest in 1723. In 1767 the industry was started in Ruhla in the Thuringian Forest, in Germany, and this town is still the most important center for the manufacture of genuine and artificial meerschaum pipe bowls and cigar holders. In 1907 between 3,000 and 4,000 workmen were employed. In 1911 it is stated that here about 1,200,000 pipe bowls and cigar holders were made, and exports were valued at about \$170,000. The production in 1911 had declined to about one-tenth of that in 1865 to 1866, due probably both to decreased demand and to competition from other centers, such as Lemgo and Nuremburg in Germany and production centers in the United States, England, and other countries.

The irregular masses of meerschaum are first roughly cut to shape, then carved by hand or turned down on lathes, then smoothed down with glass paper and dutch rushes. They are then boiled in wax, stearin, or spermaceti and polished with chalk or bone ash.

Meerschaum colors with smoking, because the mixture of the nicotine with the wax used in finishing permeates the pores of the mineral. As long as any wax remains, the color will deepen with continued smoking. When the desired color is reached, it may be "set" by removing the remaining wax and boiling in linseed oil to fill the pores and harden the mineral. The details of the color-setting process are trade secrets.

Meerschaum chips and dust are consolidated under pressure and the resultant blocks used to make artificial meerschaum pipes, etc. Good imitations of meerschaum are made by treating hardened plaster of paris with wax and coloring with gamboge or other pigments.

At Vallecas, Spain, it is stated that meerschaum is found in blocks of sufficient size and abundance so that it may be utilized as a building material. In Algeria a soft variety has been used in place of soap for the whitening of linen and in the Moorish baths. Other suggested uses are for electrical insulation; as a mild abrasive (for toothpaste, etc.); and as an absorbent for oils, greases, etc.

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MICA

The term "mica" is a group name applied to a large number of minerals that have certain physical and chemical characteristics in common. They all have a perfect basal cleavage yielding very thin, tough, more or less elastic plates or laminae. Chemically they are all silicates, usually orthosilicates of aluminum with potash and hydrogen and generally magnesium and ferrous iron. Fluorine may be an important constituent. Less common varieties contain ferric iron, sodium, and lithium, with, more rarely, rubidium and cesium. Still more uncommon varieties contain vanadium, barium, manganese, and chromium. All micas, upon heating, yield water (commonly 4 to 5 per cent, but chlorites yield 10 to 13 per cent and vermiculite 11 to 21 per cent, although they are not considered hydrosilicates).

Micas of commercial importance may be divided into two general groups: (1) those used for their physical properties, including muscovite, phlogopite, biotite, sericite, and vermiculite; and (2) those used for their chemical content, including lepidolite and zinnwaldite (lithium), and roscoelite (vanadium). In this section we will deal only with the first group, in which their physical or "micaceous" properties are important.

Composition. *Muscovite*, potash mica, $\text{H}_2\text{KAl}_3(\text{SiO}_4)_3$, is a complex silicate of potassium, aluminum, and hydrogen, also often containing sodium iron, magnesium, calcium, and fluorine.

Phlogopite, amber mica, bronze mica, magnesium mica, $(\text{K},\text{H})_3\text{Mg}_3\text{Al}(\text{SiO}_4)_3$, is a complex silicate of magnesium, aluminum, potassium, and hydrogen, also often containing iron, sodium, and fluorine.

Biotite, black mica, magnesium-iron mica, $(\text{K},\text{H})_2(\text{Mg},\text{Fe})_2(\text{Al},\text{Fe})_2(\text{SiO}_4)_3$, is a complex silicate of magnesium, iron, aluminum, potassium, and hydrogen, also often containing titanium, sodium, and fluorine.

The analyses* of muscovite, phlogopite, and biotite in Table 1 are typical.

Sericite is a fine, scaly variety of muscovite, usually occurring in fibrous aggregates, often forming nearly the entire volume of a rock mass (sericite schist). Unlike muscovite, when finely ground it often does not develop the exceedingly thin plates needed for certain high-grade uses such as paint and wall paper (see sericite).

Damourite is a fine-grained hydrous mica that has been recovered from deposits near Adelaide, South Australia, and marketed as ground mica.

Chlorite is the name of a group of micaceous minerals, usually green in color and often called the brittle micas. They resemble the true micas in appearance and cleavage; but they are usually opaque, and cleavage plates are not elastic, but are rather tough and brittle and sometimes almost sectile. The chlorites and chlorite schists are sometimes ground to make a low grade of ground mica for prepared roofing, etc.

* CLARKE, F. W., Analyses of Rocks and Minerals, *U.S. Geol. Survey, Bull.* 591, pp. 330 and 333. (Muscovite from Alexander County, N.C.; phlogopite from Burgess, Canada; biotite from Auburn, Maine.)

Mica schist is a laminated metamorphic rock consisting largely of mica (usually muscovite, biotite, or chlorite) in small flakes, mixed with quartz and other minerals. Mica schist has been used as a refractory material and it is sometimes ground to make a low grade of ground mica for prepared roofing, etc.

Vermiculite is treated in the section devoted to it.

Lepidolite and *zinnwaldite* are lithium micas discussed under Lithium Minerals. It is noteworthy that in one area only, Western Australia, lepidolite is found in large sheets. It is considered superior material for diaphragms.

Roscoelite is a vanadium mica used as a source of this metal. It has a theoretical formula $H_8K(MgFe)(AlV)_4(SiO_3)_{12}$. Commercial occurrences are in sandstones in Colorado, Utah, New Mexico, and Arizona.

TABLE 1. ANALYSES OF MICAS

	Muscovite, per cent	Phlogopite, per cent	Biotite, per cent
SiO ₂	45.40	39.66	34.67
TiO ₂	1.10	0.56	
Al ₂ O ₃	33.66	17.00	30.09
Fe ₂ O ₃	2.36	0.27	2.42
FeO.....	.....	0.20	16.14
BaO.....	.....	0.62	0.85 (MnO)
MgO.....	1.86	26.49	1.98
Na ₂ O.....	1.41	.60	1.67
K ₂ O.....	8.33	9.97	7.55
H ₂ O.....	5.46	2.99	4.64
F.....	0.69	2.24	0.28
	100.27	100.60	100.29
Less O ₂ equivalent of F.....	0.29	0.94	0.12
	99.98	99.66	100.17

General Description. The commercial micas are complex silicates of aluminum and potassium containing hydrogen, magnesium, iron, sodium, lithium, and fluorine, which crystallizes in the monoclinic system. They are characterized by a perfect basal cleavage and elastic cleavage laminae, are relatively soft, and fuse with difficulty. Thin plates are usually transparent, but thicker plates vary from transparent to opaque. Colors are white, yellow, amber, red, brown, green, gray, and black.

Physical Properties. *Muscovite.* Hardness, 2 to 3. Specific gravity, 2.8 to 3.1. Melting point, 5.7 in scale. Index of refraction, 1.561 to 1.594. Color, colorless, yellow, brown, red, green, gray. Streak, white. Luster, pearly to vitreous. Cleavage, basal only, but unusually perfect. Transparency, thin plates, transparent to translucent; thicker plates, transparent to opaque. Tenacity, elastic.

Phlogopite. Properties are the same as for muscovite, with the following exceptions: Melting point, high. Index of refraction, 1.562 to 1.606. Color, silvery brown, yellow, brown, green, copper, or bronze red.

Biotite. Properties are the same as for muscovite, with the following exceptions: *Melting point*, high. *Index of refraction*, 1.541 to 1.574. *Color*, black to dark brown or dark green.

Under heat muscovite begins to lose its valuable electrical properties at about 550°C and gives off water rapidly at 700°C. Good phlogopite will stand temperatures of up to 1000°C without losing either water or its electrical value.

Occurrence. It is of the utmost importance that any discussion of the occurrence of mica deposits of commercial interest sharply differentiate between deposits of high-grade sheet mica (muscovite or phlogopite) suitable for the most exacting electrical uses and deposits that will yield material suitable for ground mica. And in the ground-mica field we must further divide deposits into those of white mica suitable for making the best water-ground mica and the low-grade deposits that will yield only dry-ground mica of roofing grade. These three fields are distinct and noncompetitive—practically different industries. Important deposits of high-grade sheet mica are very rare; the products are of high value and will stand high transportation costs. Sources of white mica for wet grinding are distinctly not common but are far more abundant than good sheet-mica deposits. Deposits of mica schist and other low-grade micas for dry grinding are relatively common. The product has low unit value and ores will not stand high transportation costs.

Unfortunately, production statistics for all grades and types are often grouped together, particularly for some foreign countries. Grave errors in judging the world's mica reserves and of the value of individual mica deposits have arisen from lack of understanding of the basic differences between these three fields. Mineralogically and geologically, mica is a very common mineral, but important deposits of sheet mica are known in but few countries in the world. Mica suitable for grinding is much more widespread but has developed on important scale only in those countries which have enough industrial development to provide local market or which can profitably export grinding grade of scrap mica.

The modes of occurrence of muscovite and biotite are much the same, but those of phlogopite are usually quite different. Geologically, commercial muscovite and biotite occur chiefly in pegmatite dikes, associated with feldspar and quartz, but they also are abundant in granites, syenites, schists, and gneisses. Phlogopite occurs in crystalline limestones, dolomites, schists, serpentines, and basic dikes.

Prior to the Second World War India was by far the largest supplier of high-grade sheet mica. Madagascar was an important shipper of phlogopite mica. Brazil, Argentina, Canada, and the United States were relatively small but important producers. During the war, when mica was the No. 1 strategic mineral, very extensive and costly efforts were made by the United States Government to find and develop worth-while deposits all over the world then accessible to us. By this extensive effort, production was increased considerably in all the foregoing countries. Southern Rhodesia and Tanganyika became important producers and a few other countries such as Mexico and Peru made some shipments. In general, however, even with the very high prices paid,

government subsidies, and other stimulation very few important new deposits of high-grade mica were found.

United States. Taking into account all grades and types of mica, North Carolina for a great many years before, during, and since the Second World War has been by far the most important mica-producing state. Although the first commercial mica mine in the country, the famous Ruggles mine, was opened in New Hampshire in 1803 to supply "isinglass" for stove windows, that state soon lost the lead to North Carolina and only regained it once or twice for short periods. Except for the war periods the bulk of production has come from these two states, plus South Dakota and Connecticut. Mica deposits of some sort occur in a great many states. Under the vigorous government stimulation and high prices of the Second World War, a great number of deposits were opened and some yielded important quantities of lower grade, stained, and defective sheet mica suitable for less important uses. In addition, much larger quantities of mica were developed that were suitable only for grinding. Some of this war production came from previously known deposits or districts, but many new deposits were opened. Since much of this production was of poor quality and gained at impossibly high price levels, records of production for that period do not give a true picture of which states really should be called mica-producing states. In addition to the states noted above, fairly important war production of high-grade sheet mica came from Idaho, Virginia, Maine, Alabama, and perhaps New Mexico. At the peak of domestic activity in 1943 production was recorded from 16 states.

North Carolina. Mica deposits have been opened in 18 or more counties in western North Carolina in a belt about 200 miles long by 75 miles wide, running nearly northeast and southwest. This belt has been divided into three areas: (1) the Cowee-Black Mountain area, embracing parts of Macon, Jackson, Transylvania, Haywood, Buncombe, Yancey, Mitchell, Watauga, and Ashe counties; (2) the Piedmont area, including parts of Rutherford, Burke, Cleveland, Gaston, Lincoln, Catawba, and Stokes counties; and (3) the Blue Ridge area, embracing parts of Jackson, Transylvania, McDowell, Caldwell, and Wilkes counties. At present, the North Carolina mica-mining industry is largely centered about Spruce Pine.

New Hampshire. Mica mining in the United States first began in 1803 in New Hampshire and, until 1868 when production started in North Carolina, this state was the only producer. Since 1868 production on a large scale in New Hampshire has only been spasmodic, due to low prices on imported mica and on that produced by other states. During the Second World War the industry was revitalized for a brief period, but by 1946 was again nearly dormant. Mica deposits have been worked in Grafton, Cheshire, Sullivan, Merrimack, Strafford, and Coos counties, but the best deposits lie in a belt extending from Keene through the middle of Cheshire County northward into Sullivan County and the northwestern part of Merrimack County and northeast to about the center of Grafton County.

South Dakota. Production comes from the extensive pegmatites in the southern Black Hills, near Custer.

Georgia. Mica in sheets of marketable size is found in almost every county within the area of crystalline rocks in Georgia, but deposits of commercial promise are confined to comparatively few counties. Those of most importance are Cherokee, Lumpkin, Union, Rabun, Harts, and Elbert. Of less importance are Carroll, Paulding, Pickens, Oconee, Hall, Henry, Troup, Meriwether, Talbot, Upson, and Monroe counties.

Other States. Mica has been mined in *Virginia*, in Henry, Pittsylvania, Franklin, and Bedford counties; in *New Mexico*, chiefly in the Petaca district of eastern Rio Arriba County; in *Alabama*, in Tallapoosa, Randolph, Chilton, Lee, Clay, Coosa, and Cleburne counties; in *South Carolina*, chiefly in Oconee, Anderson, and Greenville counties; in *Idaho*, from the Avon district in Latah County; and in *Connecticut*, from the pegmatite dikes near Middletown.

India. India is the most important source of high-grade sheet mica in the world, normally supplying about 65 per cent or more of the world's production. With her large resources of high-grade mica and cheap labor she dominates the world's markets. The largest producing area is in Bengal, Provinces of Bihar (Kodarma district) and Orissa, which accounts for about 75 per cent of the production. Madras (Nellore district) produces about 22 per cent; Rajputana (Ajmere and Merwara districts), 2 per cent; and other provinces (in Punjab, Mysore, Coorg, Rewah, the Central Provinces, and Burma), 1 per cent. The mica industry in India is very old and the natives have become so proficient in trimming, grading, and packing mica that India mica is considered the best prepared in the world. A small percentage of the production is used locally, but most of it is exported, chiefly to England, Germany, and the United States. In addition to sheet mica India is also a large exporter of scrap mica for grinding, largely to the United States.

Brazil. Second in importance only to India as a producer of high-grade sheet mica is Brazil. Here muscovite mica occurs in a number of widely separated areas, but the most important production has come from the southeastern and eastern parts of the state of Minas Geraes. In former years important production has come from the state of Sao Paulo, and deposits of problematical commercial value are known in several other states. Unusually large, perfectly flat sheets of mica for special war uses were obtained from Brazil during the last war.

Canada. With one important exception the bulk of the mica produced in Canada has been phlogopite, and at one time Canada was the only significant producer of this type of mica. Prior to the Second World War much of this business was lost to Madagascar. During the war, when Madagascar was inaccessible, production was increased and still continues.

The phlogopite deposits of Canada are located in two districts, one with an area of about 1,200 square miles in the province of Quebec and the other of about 900 square miles in the province of Ontario. The Quebec deposits lie immediately to the north of the city of Ottawa, county of Ottawa, near or between the Lièvre and Gatineau rivers. The principal mines are in the townships of Templeton, Wakefield, Hull, and Portland, but the known deposits extend into Pontiac, Montmorency, and Wolfe counties. The deposits in Ontario are due north of the city of Kingston in Frontenac, Lenark, and Leeds counties. The principal districts

in Ontario are the Sydenham area (chief mines in Loughborough and Bedford townships) and the Stanleyville, Micaville, or Perth area (chief mines in the townships of North and South Burgess and North Crosby).

In 1941 and 1942 a remarkable and probably unique deposit of high-grade sheet muscovite mica was discovered in the township of Mattawan, Nipissing District, Ontario, a few miles north of Eau Claire between Mattawa and North Bay. This deposit, known as the Purdy Mine, contained a single crystal of mica 9.5 ft by 7 ft by about 36 in. thick, which yielded rifted sheets 62 by 75 in. and a total yield of trimmed sheets of about 7 tons. Over 30 per cent was of No. 1 Clear quality. The deposit was practically exhausted in about 2 years and was closed down after the war.

Southern Rhodesia. Important deposits of muscovite mica occur in several districts in this country, of which Miami or Lomagundi field, 120 miles northwest of Salisbury, has been the largest producer. At one time during the last war it was estimated that Southern Rhodesia supplied about 30 per cent of the United Kingdom's requirements for "clear" and "slightly stained" qualities of mica.

Madagascar. For some years prior to the Second World War Madagascar was almost the sole world producer of phlogopite mica. After the recovery of the island by the United Nations, production was resumed eventually on a small scale. Due to war damages and to pricing policies, however, production has not yet resumed prewar prominence. Madagascar also has muscovite deposits, but production has been small.

Other Countries. Other countries that made some contribution to the mica needs of the last war are Mexico (largely phlogopite), Peru, Argentina, Ceylon, and Tanganyika. Several other countries are minor producers of mica for their own use or for export as scrap.

Production and Consumption. Statistics of world production of mica are almost valueless, since all forms of mica are lumped together and only total tonnages given with no indication as to type or quality. Thus, one country producing only low-grade scrap mica may seem a more important producer than another country producing a small tonnage of high-grade sheet mica. For this reason no attempt is given here to present a world picture of mica production. The principal producing countries have been indicated already. The principal countries consuming high-grade sheet mica are those countries which have well-developed electrical industries. Prior to the Second World War Great Britain had long been the largest factor in the mica industry due both to control of India mica and to its prominence in mica fabrication and use. As India's ties with Great Britain became weaker, British hold on the mica industry has lessened, but it is still important. Before the war the industrialized countries, Europe (Germany, France, and Belgium), and Japan were important users of mica.

United States. The most important features of the domestic mica industry are shown in Tables 2 to 4 from the "Minerals Yearbook," 1946, of the U.S. Bureau of Mines.

Mining and Milling. Mica-mining operations, with but few exceptions, have always been conducted on a small scale and in an inefficient way. In India, where mica mining has been carried on for centuries by the natives, labor has always

MICA

TABLE 2. SALIENT STATISTICS OF THE MICA INDUSTRY IN THE UNITED STATES, 1942 TO 1946

	1942	1943	1944	1945	1946
Domestic mica sold or used by producers:					
Total uncut sheet and punch:					
Pounds.....	2,761,844	3,448,199	1,523,313	1,298,587	1,078,867
Value.....	\$725,030	\$3,228,742	\$3,262,711	\$737,342	\$217,955
Average per lb.....	\$0.26	\$0.94	\$2.14	\$0.57	\$0.20
Scrap:*					
Short tons.....	43,262	46,138	51,727	41,060†	53,602
Value.....	\$671,165	\$738,025	\$1,089,072	\$812,322†	\$1,041,423
Average per ton.....	\$15.51	\$16.00	\$21.05	\$19.78†	\$19.43
Total sheet and scrap:*					
Short tons.....	44,643	47,862	52,489	41,709†	54,141
Value.....	\$1,396,195	\$3,966,767	\$4,351,783	\$1,549,664†	\$1,259,378
Total ground:*					
Short tons.....	46,979	51,582	52,713	51,806†	62,113
Value.....	\$1,653,358	\$1,990,144	\$1,914,709	\$1,995,969†	\$2,516,018
Consumption of splittings:					
Pounds.....	6,636,639	8,413,362	8,816,965	7,897,402	7,815,989
Value.....	\$2,835,421	\$3,518,822	\$4,657,730	\$3,415,696	\$4,259,478
Imports for consumption:					
Total uncut sheet and punch:					
Pounds.....	3,244,857	5,501,745	5,032,983	4,284,720	4,499,562
Value.....	\$2,141,465	\$6,313,900	\$3,921,078	\$4,125,016	\$2,288,448
Scrap:					
Short tons.....	2,179	2,048	2,412	3,567	6,208
Value.....	\$25,879	\$27,102	\$32,688	\$41,410	\$75,846
Total sheet and scrap:					
Short tons.....	3,801	4,799	4,928	5,709	8,458
Value.....	\$2,167,344	\$6,341,002	\$3,953,766	\$4,166,426	\$2,364,294
Manufactured:					
Short tons.....	7,493	8,960	2,314	3,695	5,487
Value.....	\$6,860,434	\$9,513,064	\$3,707,718	\$2,172,333	\$4,754,583
Total imports:					
Short tons.....	11,294	13,759	7,242	9,405	13,945
Value.....	\$9,027,778	\$14,854,066	\$7,661,484	\$6,338,759	\$7,118,877
Exports (all classes of mica):					
Short tons.....	1,001	693	619	981	1,542
Value.....	\$303,526	\$653,889	\$526,824	\$377,473	\$709,109

* Includes mica recovered from kaolin and mica schists as follows: 1942—20,481 tons, \$315,807; 1943—24,113 tons, \$314,851; 1944—22,107 tons, \$485,567; 1945—15,046 tons, \$324,515; and 1946—15,197 tons, \$290,540.

† Revised figure.

been very cheap and good mica relatively abundant. This has resulted in mining exclusively by hand methods, even to dewatering the mines by bucket lines instead of pumps; mine openings have been very small, irregular, and often untimbered, though some mines are several hundred feet deep. Despite this fact, India mica has dominated the world markets on account of its cheapness and its high quality.

In the United States mica mining, except in a few unusual cases, has not been

TABLE 3. MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1935 TO 1939 (AVERAGE) AND 1940 TO 1946

Year	Sheet mica						Scrap mica and mica recovered from kaolin and schists		Total	
	Uncut punch and circle mica		Uncut mica larger than punch and circle		Total uncut sheet mica ^a		Short tons	Value	Short tons	Value
	Pounds	Value	Pounds	Value	Pounds	Value				
1935-1939 (avg)	888,313	\$ 46,408	252,411	\$ 139,306	1,140,724	\$ 185,714	21,986	\$ 285,512	22,557	\$ 471,226
1940	1,405,305	166,087	220,132	175,598	1,625,437	291,685	22,386	314,565	23,199	606,250
1941	2,342,237	206,947	324,216	359,911	2,666,453	566,858	32,500	442,789	33,833	1,009,647
1942	2,425,645	282,900	336,199	442,130	2,761,844	725,030	43,262	671,165	44,643	1,396,195
1943	2,691,083	473,955	757,116	2,754,787	3,448,199	3,228,742	46,138	738,025	47,862	3,966,767
1944	835,402	147,635	687,911	3,115,076	1,523,313	3,262,711	51,727	1,089,072	52,489	4,351,783
1945										
Connecticut.....	60,823	3,246	1,009	6,879	61,832	10,125	70	1,752	101	11,877
Idaho.....	33,948	11,510	14,070	99,498	48,018	111,008	199	3,178	223	114,186
New Hampshire.....	519,343	53,593	13,601	91,354	532,944	144,947	442	11,206	708	156,153
North Caroline.....	491,428	82,292	72,562	160,766	563,990	243,058	30,682	709,334	30,964 ^b	952,392 ^b
South Dakota.....	32,506	9,727	24,064	168,969	56,570	178,696	1,192	21,534	1,220	200,230
Other states ^c	28,810	5,748	6,423	43,760	35,233	49,508	8,475	65,318	8,493	114,826
	1,166,858	\$166,116	131,729	\$ 571,226	1,298,587	\$ 737,342	41,060 ^b	\$ 812,322 ^b	41,709 ^b	\$1,549,664 ^b
1946										
North Carolina.....	339,997	54,684	84,794	80,821	424,791	135,505	39,100	887,901	39,312	1,023,406
South Dakota.....	13,884	2,148	3,516	6,284	17,400	8,432	2,806	63,692	2,815	72,124
Other states ^d	633,010	69,207	3,666	4,811	636,676	74,018	11,696	89,830	12,014	163,848
	986,891	\$126,039	91,976	\$ 91,916	1,078,867	\$ 217,955	53,602	\$1,041,423	54,141	\$1,259,378

^a Includes small quantities of splittings in certain years.^b Revised.^c Includes Alabama, Arizona, California, Colorado, Georgia, Maine, Massachusetts, Nevada, New Mexico, Pennsylvania, South Carolina, Virginia, and Wyoming.^d Includes Alabama, California, Colorado, Connecticut, Georgia, Maine, New Hampshire, New York, South Carolina, and Virginia.

MICA

TABLE 4. SHEET, PUNCH, AND SCRAP MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1942 TO 1946, BY DISTRICTS

	1942	1943	1944	1945	1946	Total
Sheet:						
Southeastern:						
Pounds.....	220,108	403,257	376,757	78,510	85,525	1,164,157
Value.....	\$355,149	\$1,804,247	\$1,642,278	\$201,595	\$81,863	\$4,085,132
Northeastern:						
Pounds.....	78,108	259,584	189,492	14,624	2,901	544,709
Value.....	\$49,411	\$511,633	\$745,157	\$98,347	\$3,726	\$1,408,274
Southwestern:						
Pounds.....	2,663	4,112	1,965	390	*	9,130†
Value.....	\$1,726	\$18,433	\$11,784	\$2,660	*	\$34,603†
Northwestern:						
Pounds.....	5	5,228	38,963	14,141	.....	58,337
Value.....	\$2	\$25,939	\$247,071	\$99,655	.....	\$372,667
Black Hills:						
Pounds.....	35,315	84,935	80,734	24,064	3,516	228,564
Value.....	\$35,842	\$394,535	\$468,786	\$168,969	\$6,284	\$1,074,416
Punch:						
Southeastern:						
Pounds.....	1,563,538	1,729,573	514,698	520,118	356,797	\$4,684,724
Value.....	\$200,326	\$203,358	\$72,768	\$87,970	\$57,720	\$622,142
Northeastern:						
Pounds.....	489,436	709,740	240,546	580,166	615,972	2,635,860
Value.....	\$41,331	\$216,160	\$67,822	\$56,839	\$66,121	\$448,273
Southwestern:						
Pounds.....	8,762	2,627	4,375	.....	*	15,764†
Value.....	\$1,398	\$1,596	\$1,750	.....	*	\$4,744†
Northwestern:						
Pounds.....	.....	654	10,134	34,068	.....	44,856
Value.....	.....	\$167	\$2,055	\$11,580	.....	\$13,802
Black Hills:						
Pounds.....	363,909	248,489	65,649	32,506	13,884	724,437
Value.....	\$39,845	\$52,674	\$3,240	\$9,727	\$2,148	\$107,634
Scrap:						
Southeastern:						
Short tons.....	30,400	33,317	37,161	31,960†	40,820	173,655
Value.....	\$545,329	\$589,485	\$899,902	\$933,264†	\$931,560	\$3,899,540
Northeastern:						
Short tons.....	864	1,782	3,114	547	182	6,489
Value.....	\$17,473	\$43,550	\$74,200	\$13,797	\$1,311	\$150,331
Southwestern:						
Short tons.....	9,453	8,730	8,456	7,082	9,794	43,515
Value.....	\$63,784	\$61,372	\$55,420	\$39,749	\$44,860	\$265,185
Northwestern:						
Short tons.....	.....	75	438	279	.....	792
Value.....	.....	\$854	\$8,145	\$3,978	.....	\$12,977
Black Hills:						
Short tons.....	2,545	2,234	2,558	1,192	2,806	11,335
Value.....	\$44,579	\$42,764	\$51,405	\$21,534	\$63,692	\$223,974

* Data not available for publication.

† Figures for 1942 to 1945, inclusive. Data for 1946 not available for publication.

‡ Revised figure.

profitable. This has been due in part to the excellent quality and low prices of India mica and in part to irregularity of markets and prices. These are not the only reasons, however. Experience during the Second World War, with very high prices and every conceivable government assistance in the way of subsidy, advances against future deliveries, rental of machinery and equipment at nominal rates, government mica-trimming and buying stations, showed that our known deposits of high-grade mica are entirely inadequate to supply our needs even at uneconomic price levels. This experience only confirmed that of one of the largest electric companies who attempted systematic mica mining on a large scale in South Dakota in 1908 to 1911 and finally abandoned the venture.

These conditions have not encouraged mica mining on a large scale, that is, with backing by adequate capital, and most of the domestic mica in the past has been obtained by "ground-hogging" methods. In many cases very small openings have been made by farmers in a most haphazard way. These "mines" have been worked for a short time and then abandoned on account of lack of market, apparent exhaustion of ore, flooding, or other reasons. Since timbering is not common in such openings, they soon cave in and reopening is difficult. In these small mines the mica is located at the surface and followed down into the ground in irregular openings. Drilling is usually done by compressed-air drills with gasoline-driven air compressors, but considerable hand drilling is still done.

Care must be exercised in drilling and shooting so as not to injure crystals of mica. Very few mica deposits are sufficiently large and regular that they may be developed by a regular system of shafts, drifts, tunnels and crosscuts. Mines of this type have been worked to a depth of over 500 ft.

In Canada, open-pit methods are more common than underground mining methods. Such pits are frequently carried to a depth of 80 to 100 ft.

In most mica deposits (except for the phlogopite deposits of Canada) feldspar and quartz occur in abundance as the chief gangue minerals. In some cases the feldspar, if sufficiently pure, may serve as a valuable by-product. In a few cases the situation is reversed, as at the Deer Park Mine near Spruce Pine, N.C., and near Middletown, Conn., where large quantities of high-grade mica are obtained as by-products of feldspar mines.

Mine-run mica, consisting of rough crystals and blocks ranging in size from a few inches across up to 1 or 2 ft or even more, is first roughly sorted and then taken to a cobbing shed, where the crystals are split and freed from rock and worthless mica by hammering and cutting. The further treatment of mica has been described briefly by the Tariff Commission,¹⁵ from which the following is taken in part. Wierum³¹ has described these processes in much greater detail in a later publication of the Tariff Commission.

The mica sheets are then sent to the trimming shop or "culling shed," where they undergo a further cleaning and splitting. The rough edges are cut off and the plates are graded according to size and quality. The sheets that go from the trimming shop are what are known as "thumb-trimmed." The proportion of "thumb-trimmed" mineral to the "run-of-mine" taken to the cobbing shed is usually from 3 to 10 per cent; 5 per cent would be a good average.

These sheets, which are sometimes several inches in thickness, are broken by a

hammer into plates about $\frac{1}{4}$ in. thick. The edges of the plates are then hammered to loosen the laminae for the insertion of the splitting knife. The mica sheets are split into thicknesses of about $\frac{1}{16}$ in. and their edges are trimmed off so that only clean plates, perfect to the edges, remain. Domestic mica preparation at the mines or local trimming shops usually does not go beyond this point. Where labor is plentiful and very cheap as in India, in Canada at times in the past, in Madagascar, and in Mexico during and since the last war, a further very thin splitting is done, particularly of the small sizes.

In the trade, "sheet" or "block" mica may range in thickness from $\frac{1}{8}$ down to 0.01 in.; mica "films" range from 0.009 down to 0.001 in.; and "splittings" must be 0.001 in. or thinner.

The tools used in a mica shop are few and very simple. They consist of hammers, splitting and trimming knives, shears, and occasionally a guillotine machine. An inspection table provided with a translucent glass top and underneath illumination is useful for detection of minor flaws and imperfections.

Principal Products. *Sheet Mica.* In the trade sheet mica is divided into 10 or 12 grades based on size. (Grade in the mica industry means size.) These grades range from about 1 by 1 in. up to 8 by 10 in. or even larger. Size refers to the largest rectangle of perfect, usable mica that can be cut from a sheet, not to the over-all dimensions. Each grade is divided further into four to six classes based on quality, and still further divisions are sometimes based on color. No uniform standards of grading and quality classification exist between the principal shipping countries. Thus, we have separate systems of grading and classification in the United States, Canada, Madagascar, and India (two: Bengal and Madras). In addition we have different styles of trimming (such as thumb-trimmed, knife-trimmed, and sickle-trimmed) and of packing (such as pan-packed for splittings). All this makes the mica industry an exceedingly complicated business, understood only by experts of long experience.

Splittings. Both in tonnage and in value mica splittings today form the most important segment of the mica industry, although during the war it was not so vital strategically as sheet mica for capacitor films. Splittings are thin mica sheets, not over 0.001 in. thick, usually of small size (1 by 1 in. up to about 2 by 3 in.), generally split by hand labor from inferior-quality block mica which, in the United States, probably would go into scrap. Many costly attempts have been made to develop a practical mica-splitting machine with no real success until the war period, when several fairly successful machines were developed. By far the bulk of splittings used today, however, are imported splittings made by cheap hand labor. Mica splittings are used in making built-up mica products: mica board, tape, and cloth.

Mica Plate or Board. Built-up mica plate is made by scattering a uniform layer of splittings over a paper bottom sheet or a wire screen; covering this layer with shellac, varnish, or a synthetic plastic binder; and repeatedly adding alternate layers of splittings and binder until the desired thickness is reached. Finished thickness ranges from 0.004 to over 0.500 in. The sheets, usually 18 by 36 or 36 in. square, are then baked to set the binder, pressed in hydraulic presses

heated by steam, and finally sanded to uniform thickness and flatness and trimmed to exact size.

Mica Paper, Cloth, and Tape. These products, used for electrical-insulation windings, are thin, flexible built-up mica products made, much as described above, from splittings plus binder between thin sheets of rice paper, cloth, or silk.

The size of the splittings and built-up mica business is indicated by Table 5 from the U.S. Bureau of Mines' "Minerals Yearbook."

TABLE 5. CONSUMPTION AND STOCKS OF MICA SPLITTINGS IN THE UNITED STATES, 1942 TO 1946, BY SOURCES, AS REPORTED BY CONSUMERS

Year	Indian		Canadian		Madagascan		Total	
	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value
Consumption:								
1942	5,998,614	\$2,415,709	117,295	\$ 79,752	520,730	\$339,960	6,636,639	\$2,835,421
1943	7,649,596	3,054,995	344,966	172,674	337,099	233,788	8,413,362*	3,518,822*
1944	7,708,253	4,002,010	601,661	324,631	371,972	251,945	8,816,965*	4,657,730*
1945	7,085,316	2,970,013	321,216	163,658	324,383	188,530	7,897,402*	3,415,696*
1946	7,243,835	3,939,595	292,212	152,969	217,309	130,040	7,815,989*	4,259,478*
Stocks in consumers' hands Dec. 31:								
1942	8,202,240	3,367,788	257,591	178,082	321,529	201,274	8,781,360	3,747,144
1943	4,031,849	1,708,096	138,564	85,893	215,639	139,797	4,517,211*	2,032,758*
1944	3,578,885	1,749,011	141,427	95,850	184,970	121,307	3,994,977*	2,025,165*
1945	2,684,848	1,145,176	143,102	91,115	193,763	130,661	3,064,589*	1,391,617*
1946	5,727,615	3,039,429	275,685	166,786	535,185	378,174	6,588,932*	3,615,731*

* Totals for 1943 to 1946 include relatively small amounts of domestic and Mexican splittings.

Scrap and Ground Mica. In the United States virtually the only use for scrap mica is for the making of ground mica. In India, with very cheap labor, it pays to work over scrap and turn a part of it into splittings, but that cannot be done profitably in this country.

For the making of ground mica the following sources are utilized:

Shop scrap, resulting from punching and trimming of sheet mica for ultimate use, usually rifted and free from rock, of highest quality and commanding highest prices.

Mine scrap, distorted and imperfect book mica not suitable for sheet mica, usually more or less discolored and containing adhering rock fragments and clay. By-product of mica or feldspar mining or deliberately mined as scrap.

By-product from kaolin washing, finely divided.

By-product from flotation of feldspar.

Mica schists, which are the lowest grade product. Often a mixture of muscovite and biotite, or chlorite, with feldspar and quartz grains.

Table 6 from the U.S. Bureau of Mines' "Minerals Yearbook" shows the domestic production of scrap mica. In Table 6 "Reclaimed" means by-product

TABLE 6. SCRAP AND RECLAIMED MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1935 TO 1939 (AVERAGE) AND 1943 TO 1948

Year	Scrap		Reclaimed		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1935-1939 (avg)	13,582	\$168,688	8,404	\$116,824	21,986	\$ 285,512
1943	22,025	423,174	24,113	314,851	46,138	738,025
1944	29,620	603,505	22,107	485,567	51,727	1,089,072
1945*	26,014	487,807	15,046	324,515	41,060	812,322
1946	38,405	750,883	15,197	290,540	53,602	1,041,423
1947	35,199	709,745	14,598	385,833	49,797	1,095,578
1948	.....	.....	.....	.....	52,157	1,091,698

* Revised figures.

mica from kaolin washing and feldspar flotation plus mica schist. In addition to domestic production of scrap mica there were imports totaling over 6,000 tons in 1948 from India, Canada, Union of South Africa, Peru, Mexico, Tanganyika, Portuguese East Africa, and Angola.

The best grades of ground mica are made from selected shop scrap and are wet ground. This wet-ground mica is cleaner and of better luster, and consists of flatter, thinner plates than can be obtained in dry grinding. Dry grinding tends to roughen and burr up the edges of the plates and destroys some of the slip and luster. Also, dry-ground mica made from scrap or mica schist may contain more gritty impurities.

Wet grinding is done in batches in wooden or wood-lined tubs containing wooden grinding wheels that rotate in either a vertical or a horizontal plane. After grinding has been done for from 4 to 12 hr, the water is drawn off and the mica spread on cloths over steam pipes. The dried mica is then disintegrated and bolted, the oversize being returned for regrinding. Numerous costly attempts have been made to develop more efficient, continuous-grinding systems, but none have been successful. The only improvements have been in details of the old methods.

Dry grinding is most commonly done in high-speed disintegrators or hammer mills, followed by screening or bolting or by close sizing in air separators, although ball mills are sometimes used. Mica flakes are very tough and resilient; they are very difficult to grind and cause high abrasive wear on grinding surfaces and chutes.

By-product mica from kaolin washing and feldspar flotation may be simply dried, sized, and sold without grinding.

Ground mica is sold in mesh sizes ranging from 8 to 325 mesh.

The most important uses for ground mica are as a surfacing agent in prepared roofing, as an ingredient in paints, as a dusting and lubricating agent in rubber, and as a decorative material in wallpaper printing. In paints the thin mica

flakes plate on each other, like roofing slates, and make a continuous, protective film. This use has become very important and is still growing.

United States production of ground mica and distribution by uses are shown in Tables 7 and 8 from the U.S. Bureau of Mines' "Minerals Yearbook."

TABLE 7. GROUND MICA (INCLUDING MICA FROM KAOLIN AND SCHISTS) SOLD BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948, BY METHODS OF GRINDING

Year	Dry-ground		Wet-ground		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944	47,023	\$1,382,147	5,690	\$ 532,562	52,713	\$1,914,709
1945	43,686	1,243,075	8,120	752,894	51,806	1,995,969
1946	53,908	1,582,974	8,205	933,044	62,113	2,416,018
1947	55,731	1,852,768	8,809	1,114,945	64,540	2,967,713
1948	55,494	2,035,618	9,148	1,197,014	64,642	3,232,632

TABLE 8. GROUND MICA (INCLUDING MICA FROM KAOLIN AND SCHISTS) SOLD BY PRODUCERS IN THE UNITED STATES TO VARIOUS INDUSTRIES, 1945 TO 1946

Industry	1945			1946		
	Quantity		Value	Quantity		Value
	Short tons	Per cent of total		Short tons	Per cent of total	
Roofing.....	28,407*	155*	\$ 711,175*	30,102	48	\$ 791,639
Wallpaper.....	1,911	4	139,719	2,827	5	240,786
Rubber.....	3,715	7	241,657	4,951	8	381,231
Paint.....	7,570	14*	382,992	14,452	23	638,598
Plastics.....	990	2	83,941	321	1	33,066
Miscellaneous† ..	9,213	18*	436,485	9,460	15	430,698
	51,806*	100	\$1,995,969*	62,113	100	\$2,516,018

* Revised.

† Included mica used for molded electric insulation, house insulation, Christmas-tree snow, manufacture of axle greases and oil, annealing, pipe-line enamel, textiles, oil-well drilling, welding, and other purposes.

Markets and Prices. Several of the largest users of sheet mica buy a large part of their needs in the form of full-trimmed or partly trimmed sheet direct from producers abroad, from importers, and from domestic producers, and do their own fabricating. Very important factors in the industry, however, are mica fabricators who buy sheet mica and work it up into finished parts made to specification for each user. These parts, consisting of washers, disks, condenser

films, insulating plates, and special shapes for a multitude of uses, chiefly electrical, are made by punching, shearing, turning, and stamping.

Crude mica, trimmed sheets, washers, splittings, etc., are sold by the pound, but all special shapes are sold by the piece. Ground mica is sold at a price per short ton and is shipped in bags.

Table 9 from the Bureau of Mines shows prices realized for domestic mica in 1946 compared with printed quotations.

TABLE 9. TRADE-JOURNAL QUOTATIONS AND AVERAGE SALES VALUE OF DOMESTIC UNCUT SHEET MICA PER POUND IN 1946

Size	Trade-journal quotations,* Nov. 28, 1946	Average value†	
		Clear	Stained or spotted
Punch.....	\$0.22	\$0.13	\$0.14
1½ × 2 in.....	1.10	0.96	0.54
2 × 2 in.....	1.60	1.47	0.86
2 × 3 in.....	2.10	2.00	1.68
3 × 3 in.....	2.75	2.61	1.90
3 × 4 in.....	3.50	3.00	2.80
3 × 5 in.....	4.00	3.71	3.01
4 × 6 in.....	5.00	4.48	4.03
6 × 8 in.....	.....	5.67	5.08
8 × 10 in.....	.....	8.15	

* *Eng. Mining J.*, *Metal Mineral Markets* quotations fob North Carolina.

† Calculated from sales by domestic producers as reported to the Bureau of Mines.

Clear sheet mica, dimensions in inches, was quoted in 1950 per pound as follows:

1½ × 2	\$0.70-0.75
2 × 2	0.95-1.00
2 × 3	1.35
3 × 3	1.80
3 × 4	2.25
3 × 5	2.50
4 × 6	3.25
6 × 8	4.50

Stained or electric sheet 10 to 15 per cent less than clear. Wet ground, \$120 to \$135 per ton dependent on quality. Dry ground, \$32 to \$70 per ton dependent on quality. Scrap, \$30 to \$35 per ton.

Grades, Specifications, and Tests. No generally accepted specifications exist for mica for various uses, but each customer usually has empirical standards to fit his own needs. Houk states:

Block mica must be free from structural imperfections (cross-grains, cracks, reeves, and ribs) and mineral inclusions (black or red spots, mineral stains or streaks) to have

strategic importance. It must be clear, flat, hard, and capable of being separated easily into thin films or sheets (1 mil or 0.001 in. in thickness) of uniform thickness over the entire area without the development of an excessive proportion of partial films. Structural imperfections cause the mica to split unevenly, producing imperfect films, and inclusions reduce its electrical resistance and power factor.

Mica, moderately stained with metal oxides, may be satisfactory for some dielectric uses, but mineral staining of any type renders it unfit for use in electrical condensers. The presence of numerous small air bubbles makes mica unsuitable for condenser use. Large air bells may be removed by careful splitting. Clay stains occur in mica only near the surface of deposits and render it suitable only for scrap. The chemical analysis of block muscovite affords no indication of its commercial value or possible use.

The specifications vary with use. For high-grade condenser work a low power factor is the determining element. In electrical power generation dielectric strength and resistance to heat are important. For "cigarette" mica used in aviation spark plugs, flexibility is one of the deciding factors. "Cigarette" mica consists of films less than 1.2 mils in thickness that can be rolled around a $\frac{1}{8}$ -in. spindle without cracking or tearing and be free of pinholes and hairline cracks. Nose washers on airplane spark plugs are made of high-heat-resistance phlogopite mica. Good condenser mica should have a power factor of 0.03 per cent or less. A good dielectric mica should withstand at least 1,000 volts per mil of thickness of 4 to 6 mils when tested with 2-in. plate electrodes. Almost any mica will withstand 500 to 600°C without appreciable change.¹¹

Prior to the Second World War the quality of sheet mica was judged almost wholly by visual inspection. Since mica was cheap and abundant, qualification was very rigid and much mica was de-graded for imperfections so slight as to be invisible to the untrained observer. During the war when acute shortages made mica the No. 1. strategic mineral it was thought that some quick, accurate method of electrical testing, if it could be developed, might show that considerable mica, not acceptable as strategic mica under visual inspection test, might really be of strategic quality. This thought led eventually to the development by the Bell Telephone Laboratories of two portable testing machines, one for testing dielectric strength (absence of conducting particles) and the other to measure dielectric loss or power factor. Extensive tests proved the accuracy of these machines and new ASTM specifications for capacitor mica based on their use were adopted. It was reported that 60 per cent of the stained and other mica formerly rejected by the visual test could be used for capacitors.

For ordinary mica washers and other low-duty electrical uses the lower qualities of stained and less perfect mica are entirely acceptable.

Classification. Grade (size) standards for sheet mica used in the principal producing countries are not the same and cannot even be correlated accurately with each other, even by experts. However, Table 10 by Wierum³¹ gives a fairly accurate picture of grade classifications used in the trade.

Classification by quality is also not standardized, but due to the fact that the bulk of the sheet mica used by domestic industry comes from India, the American

TABLE 10. STANDARD GRADE DIMENSIONS OF SHEET MICA IN THE UNITED STATES, CANADA, INDIA, AND MADAGASCAR

United States, in.	Canada, in.	India				Madagascar	
		Bengal		Madras			
		Grade	Sq in.	Grade	Sq in.	Grade	Sq in.
8 × 10	.....	..... Extra special	..... 48 and up	IX VIII VII VI	96-112 80-96 64-80 48-64	00	Over 48
6 × 8	5 × 8	Specials	36-48	V	32-48	0	36-48
6 × 6	.....	No. 1	24-36	.....	.....	1	24-36
4 × 6	4 × 6	No. 2	15-24	IV	16-32	2	15-24
3 × 5	3 × 5	No. 3	10-15	III	8-16	3	10-15
3 × 4	.....	No. 4	6-10	.....	.....	4	6-10
3 × 3	2 × 4	No. 5	3-6	II	4-8	5	3-6
2 × 3	2 × 3	No. 5½	2½-3				
2 × 2	1 × 3	.....	.....	I	4 and less		
1½ × 2	1 × 2	No. 6	1-2½	.....	.....	6	1-3
Circle*	1 × 1	No. 7	1 and less	.....	.....	Smaller	
Punch†							

* Larger than punch up to 2 in. in diameter.

† Yield circle 1¼ in. in diameter if clear, or 1½ in. in diameter if stained.

Society for Testing Materials adopted a quality classification substantially Indian.

ASTM D351-33T (MICA)

<i>Grading for Quality</i>	<i>Description</i>
Clear (Cl.).....	Free of all mineral and vegetable inclusions, stains, air inclusions, waves, or buckles. Hard transparent sheets
Clear and slightly stained (Cl. SS.).....	Free of all mineral and vegetable inclusions, cracks, waves, and buckles, but may contain slight stains and air inclusions
Fair stained (F.S.).....	Free of mineral and vegetable inclusions and cracks. Hard. Contains slight air inclusions and is slightly wavy
Good stained.....	Free of mineral inclusions and cracks, but contains air inclusions and some vegetable inclusions, and may be somewhat wavy
Stained (S.).....	Free of mineral inclusions and cracks, but may contain considerable clay and vegetable stains, and may be more wavy and softer than the better qualities
Black stained* or spotted.....	Same as stained but contains mineral inclusions.

* In India this item is subdivided into four graduations, namely, heavy stained, black spotted, black stained, and badly stained.

North Carolina quality classification corresponds to the qualities shown in the foregoing table about as follows:

<i>North Carolina Grade</i>	<i>Indian Equivalent</i>
No. 1.....	Equal to from Clear down to and including Good Stained
No. 2.....	Equal to Stained and Black stained or spotted, subgrade Heavy stained
No. 3 or Electric...	Equal to last three qualities of Black Stained or spotted

Utilization. By far the most important present-day uses for sheet mica and built-up mica products are in electrical insulation. Until or unless adequate substitutes for mica for critical uses, such as in capacitors, are developed mica will remain, in war and in peacetime, an absolute essential to the electrical industry in most of its ramifications. Nonelectrical uses formerly important, such as for stove fronts and for gas-lamp chimneys, are today of little importance. The following classification of uses by Schaller,* however, is still useful since it is based on function.

Electric Insulation. Sheets, films, mica board, washers, mica cloth, and tape, for dynamos, condensers, telephones, light sockets, spark plugs, and innumerable other electric appliances. Ground mica mixed with shellac is molded into various insulating forms.

Heat Insulation. Screens in front of highly heated material, as a retarder of heat waves in optical lanterns and in electric heating devices. Ground mica is used as pipe and boiler coverings, in annealing steel, and in fireproof paints and coverings.

Transparency. Glazing the fronts of stoves, for furnace sightholes, lamp chimneys, lamp shades, military lanterns, lantern slides, spectacles, sightholes of divers' helmets, compass cards, gage fronts, in windows where glass would be broken by heavy shocks or vibrations, and as coverings for wounds.

Resonance. Phonograph diaphragms and various sounding devices (submarine detectors).

Decoration. Sheets of mica form the material on which pictures and portraits are painted and are also used for inlay work. Ground mica is used extensively for decoration in wallpaper, processional ornaments, fancy paints, ornamental tiles, and concrete.

Lubrication. For wooden and metal bearings, tire powder.

Filler. Paints, patent roofing material, rubber goods, buttons, absorbent for nitroglycerin, and various other products.

Miscellaneous. Calico printing, to prevent sticking of tar papers, medicinal uses (India only).

Synthetic Mica and Mica Substitutes. During the Second World War the critical shortage of high-grade sheet mica for essential military and civilian use led to an intensive search for suitable substitutes. In some cases high-grade electrical porcelain could be used, but it necessitated the complete redesign of many parts due to the greater bulk of porcelain insulators. Eventually porcelain

* See W. T. Schaller: Mica, *Mineral Resources of the United States*, Pt. 2, pp. 655-657, U.S. Geol. Survey, 1918. Also O. Bowles: The Marketing of Mica, *Eng. Mining J.-Press*, Vol. 115, No. 2, pp. 55-60, Jan. 13, 1923.

replaced mica in most airplane spark plugs, although mica has been retained in some types of planes. For certain types of condensers paper impregnated with suitable plastic resins replaced mica. The difficulty with synthetic resins has been that they have poor resistance to high temperatures, poor dimensional stability, and inadequate imperviousness to moisture. Resins, improved in all these qualities, have been developed and with them an increasing range of mica substitutes. Other substitutes now available include woven glass tape with or without synthetic resins and ground mica bonded with glass under high heat and pressure.

Alsifilm, invented and patented in 1938 by Dr. E. A. Hauser of the Massachusetts Institute of Technology, is a synthetic product somewhat resembling mica in composition and physical properties. It is made from bentonite by special techniques. It seemed to have distinct possibilities as a mica substitute at the start, but inherent defects, such as brittleness, could not be overcome and it never has been used commercially.

Synthetic mica was made by Germany during the Second World War and used for heavy-duty condensers where natural mica had failed. It was made by melting a mixture of aluminum oxide, magnesium oxide, sand, and potassium silicofluoride in crucibles and very slowly cooling the melt. Sheets up to 62 sq in. in area of perfect mica reportedly were made at a cost of about 10 times that of imported natural mica. Integrated mica, produced by splitting mica under controlled conditions and using the natural attraction of the mica surface plus a plastic binder, was reported to be available in 1950 in large sheets.

While it is improbable that mica substitutes and synthetic mica will ever entirely replace natural high-grade mica, our dependence on natural mica will not again be so complete as it was at the start of the last war.

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MINERAL FILLERS AND ADSORBENTS

Many finely divided minerals are used as fillers and adsorbents. As fillers their service is essentially physical. As adsorbents some chemical forces come into play such as are associated with surface chemistry. Some chemical change may be produced in the material in contact with the adsorbent. There is a small and definite amount of overlap in the two functions and therefore they are treated together.

MINERAL FILLERS

In the manufacture of many industrial products, such as paper, rubber, paint, linoleum, and so on, finely ground materials, often of mineral origin, are introduced in order to give body, opacity, or some other useful property to the finished product. Sometimes such materials are also used as inert diluents without in any way impairing the quality of the finished products. Such materials are called "fillers" or, in paints, "inert extenders." A very wide range of fillers are used, often more or less interchangeably, and fillers are used in a wide range of products.

It must be understood that the fillers generally are not adulterants but introduce desirable and often necessary properties in the commodities to which they are added. Sand and gravel may be considered as coarse mineral fillers added to portland cement to produce concrete with properties superior to those of the raw materials of which it is composed. Similarly, the addition of carbon black or fumed silica to rubber in tire manufacture results in a final product of greatly improved performance. They also serve an important purpose as a diluent and distributing agent. Pure chemical compounds cannot be applied directly to the soil as fertilizers for fear of killing the plants that they are supposed to nourish. They must be diluted for ordinary use with an inert extender that aids in uniform distribution. A filler must be added. This increases weight and bulk and often freight charges to the user, but it results in the delivery of a commodity that can be used with common discretion without damage. A similar condition exists in insecticides in which the pure material is too toxic or wasteful in use unless reduced to proper dilution by the addition of inerts. A wide range of fillers may be used, sometimes interchangeably, and the user will buy the lowest priced material that will serve. The total tonnage consumed annually in the United States is not accurately known, but it is estimated to be substantially in excess of 1 million tons.

Functions of Fillers. Most fillers, except for such very low-grade uses as fertilizer filler where sand may be used, are 200 mesh and finer. The lower limit of fineness may be carbon black (channel) with a grain size of about $0.01\ \mu$. This represents a 7,000-fold range in particle size, which may explain in part why fillers are not even more interchangeable. Most fillers perform several functions, and in developing a filler for any intended use it is of greatest importance to know and understand those functions and, if possible, to measure them quantitatively. The field of fillers overlaps that of the pigments. In fact, the finely divided fillers used in the rubber industry are known to that industry as rubber pigments.

Some of the functions performed by fillers are noted below.

1. *Filler*, simple inert diluent
2. *Reinforcing agent*, adding to strength and wear (rubber)
3. *Hiding and opacifying* (paper filler, paints, enamels)
4. *Tinting* (paint)
5. *Coloring* (paint top tone)
6. *Bodying or suspending other pigments* (paint)
7. *Anticorrosion and antiweathering* (paint)
8. *Electrical functioning* (electrically conducting rubber)
9. *Lubricating and heat transfer* (graphite lubricant)
10. *Densifying or weighting agent* (barite in well-drilling mud)
11. *Insulation*, heat, sound, and electrical (loose-fill insulation)
12. *Abrasive* (soaps and polishes)
13. *Carrier* (insecticides)
14. *Surface conditioner* (paper coating)
15. *Absorbent* (floor-treating compounds)

This list probably could be considerably extended.

Materials Used as Fillers.

1. Rock dusts. By-products of the crushing and grinding of rocks:

Limestone	Marble
Gypsum	Shale
Sandstone	Trap rock
Granite	

2. Natural mineral fillers. Ground to desired size:

"Aluminum flake" (clay)	Limestone
Anhydrite	Magnesite
Apatite	Marble dust
Asbestos powder	Mica
Asbestine (talc)	Ocher and umber
Barytes	Pumice
Bentonite	Pyrophyllite
Calcite	Rottenstone
Celestite	Sand
Chalk	Serpentine
Clay	Shale
Coal (powdered)	Silica
Diatomaceous earth	Slate flour
Dolomite	Soapstone
Feldspar	Sulfur
Flint	Talc
Fuller's earth	"Talckene" (red shale)
Graphite	Terra alba (ground gypsum)
Gypsum	Tripoli
Iron oxides	Whiting

3. Industrial by-products:

Precipitated calcium carbonate
 Precipitated calcium sulfate
 Fly ash (from boiler plants)

4. Manufactured fillers:

Alumina, precipitated	Magnesia (basic magnesium carbonate)
Blanc fixe	Pearl filler
Calcium carbonate, precipitated	Pearl hardening
Calcium silicate, precipitated	Portland cement
Calcium sulfate, precipitated	Satin white
Carbon black	Silica fume
Flake white (basic carbonate white lead)	Titanium dioxide
Gypsum, dead-burned	White lead, basic carbonate
Lime, hydrated	White lead, basic sulfate
Lithopone	Zinc oxide

5. Organic materials:

Coal
 Shell
 Wood flour

Practically all the natural mineral fillers and most of the manufactured fillers are described under various headings in this work (see index). Some of the manufactured fillers not elsewhere described are treated briefly below.

Calcium sulfate (precipitated) may be made by precipitation from a solution of calcium chloride by means of glauber salts (sodium sulfate). It is obtained as a by-product in many chemical processes and may be obtained in large quantities at a fairly low price. It contains no water of crystallization (as does pearl hardening) and is thus equivalent to an artificial anhydrite. It is used in the manufacture of paper, as a filler in paints, and for other purposes. Dead-burned gypsum is used similarly.

Pearl filler is a fine-grained filler made by grinding waste made in manufacturing pearl buttons from oyster shells. It is used principally as a filler in high-grade coated papers.

Satin white may be regarded as a calcium aluminate mixed with hydrated calcium sulfate, or as a gelatinous aluminum hydroxide mixed with calcium sulfate and containing some free lime. It is an important white pigment of particular value in making coated paper and lake colors. The process of manufacture is simple, but physical conditions must be carefully regulated in order to make a high-grade product. Briefly, the process consists of slaking lime in boiling water, adding the correct proportion of finely pulverized aluminum sulfate, heating until the mass is nearly solid, adding water, and agitating thoroughly.

Pearl hardening is a trade name used to designate an artificial crystallized calcium sulfate containing water of hydration ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), and is thus equivalent to an artificial gypsum. It may be produced by adding sulfuric acid or sodium sulfate to a solution of calcium chloride, the resulting calcium sulfate

crystallizing out. It is used as a filler in the better grades of paper. *Crown filler* is another name for pearl hardening.

Products and Processes in Which Fillers Are Used. It would be difficult to give anything like a complete list of the products and industries in which fillers are used, and it would be still more difficult to enumerate all the fillers used in each product. For many and probably for most purposes a considerable number of different fillers may be used almost interchangeably. In the following list are some of the more important products and processes in which fillers are used:

Artificial stone	Insulating compounds	Plasters
Asphalt surfacing	Leather	Plastics
Cements	Linoleum and oilcloth	Putty
Ceramics	Lubricants	Roofing materials
Cordage	Matches	Rubber
Dry batteries	Oxychloride cement	Soap
Dynamite	Paint	Textiles
Fertilizers	Paper	Tooth powder and paste
Flooring compounds	Phonograph records	Wood finishing
Foundry facings	Pipe coverings	
Insecticides		

Specifications and Tests. Very few standard specifications and tests have been devised for filler materials, even for the more important uses. Each consumer has his own ideas of the properties that a material must possess in order to fit it for his use, but there are wide diversities of opinion among manufacturers of identical products. In examining a new filler material, the consumer first notes its general appearance, its color, brilliancy, and texture. If it passes these tests, he may next make approximate qualitative tests by screening, by working up with linseed oil, by noting its behavior (suspension) in water, and so on. If these tests are also favorable, often the next step is to make up a small batch of his product, using the new filler, noting its behavior and testing the quality of the finished product. In the last analysis this semicommercial plant test is the basis on which the suitability of the material is judged. If the filler compares favorably with those already in use, the selection is based almost wholly on the comparative delivered costs of the competitive materials.

For most purposes only physical properties are important, provided that the filler is chemically stable and inert under ordinary conditions. Usually chemical composition is not important, but in a few cases some impurities are considered harmful.

Of the common physical properties of fillers, probably fineness is the most important. For many uses only that portion of the filler which will pass through a 300-mesh screen is of value, and those fillers which have the very finest grain size are of the greatest value. Thus, the great value of carbon black and zinc oxide as rubber fillers probably is very largely dependent upon their extreme fineness. These fillers are very much finer than any natural, artificially pulverized materials. Not only must most of the filler be of great fineness, but it must also contain no coarse oversize or "grit." Thus, a filler, 98 per cent of which will pass through a 300-mesh screen, is valueless for some purposes if the remaining

MINERAL FILLERS AND ADSORBENTS

2 per cent is so coarse that it will not pass a 100-mesh screen. In grinding mineral fillers, this point must be always kept in mind.

The physical property second in importance is usually color. For many uses, as in high-grade paper and paints, a pure, clear-white color is demanded. For other uses, as in rubber and road asphalt-surfacing mixtures, color is of little importance.

In attempting to prepare and market mineral fillers, the two all-important factors are (1) that the product must conform to the consumers' requirements and not to fixed standards; and (2) that most markets for fillers are highly competitive and the new product must compete on a delivered-price basis not only with the same material produced by others but also with several different competitive materials.

Recent efforts in research have been directed toward the production of superfine fillers. Fumed silica obtained by the combustion of ethyl silicate has been found a satisfactory substitute for carbon black, increasing tear- and abrasion-resistance without changing color or translucency.⁷ A fine form of silica, 99.9 per cent silica, particle size 0.01 to 0.05 μ , was produced by the Linde Air Products Co. in 1947 in pilot-plant quantities.⁸ This material disperses readily in most liquids and stable, colloidal gels can be prepared. It has many industrial potentials as a catalyst carrier, pigment disperser, flattening agent, and in the rubber and textile industries.

MINERAL ADSORBENTS

The phenomenon of adsorption is not entirely understood. It is concerned with the forces active in surface chemistry that result in the concentration of gases, liquids, or dissolved substances on the surfaces of solids. Solutions or liquids in contact with an adsorptive solid may be clarified or otherwise benefited with great improvement in appearance and increase in value or dangerous gases may be removed from the atmosphere. Adsorption and absorption are closely associated, and at times it is difficult to differentiate between them. Adsorption deals with the effects of surface accumulations, and absorption is concerned with the penetration of a solid producing a change. Adsorption may be accompanied by chemical reaction, exothermic in nature, so that the amount of heat released may be substantial.

An efficient adsorbent should possess certain properties. It should be porous, with a high surface exposure, and the pores should be of proper size. It should not be too dense, which reduces efficiency. It should be resistant to the temperatures employed, which may be relatively high. A number of minerals qualify, and their use and service to industry increase. Charcoal and then other forms of carbon were among the first adsorbents to find industrial use. They were employed in the purification of sugar solutions. The use of gas as a military weapon in the First World War led to the development of gas masks whose usefulness was in part due to the use of specially activated carbon. The problem of purification of water, solutions, and liquids such as oil became common to many industries. Filtering through an adsorptive medium is most effective. The filtering action is in part mechanical, that is, suspended solids are trapped in the

fine spaces between the particles of filtering medium and removed. At the same time small percentages of objectionable materials may be removed entirely or the imperfectly understood chemical reactions incident to surface conditions may improve the quality of the filtrate.

The most commonly employed mineral adsorbents are the bleaching clays, fuller's earth and bentonite; activated clays; diatomaceous earth; bauxite; and silica gel. These materials have been discussed in other sections and the following notes deal only with their roles as adsorbents. In the petroleum industry adsorbents are used to improve the quality of lubricating oils and motor fuels. Two processes are employed. In the percolation process a tall, cylindrical column is filled with a coarse adsorbent through which the oil, in liquid or vapor phase, is forced to percolate. In contact filtration the clay and oil are mixed intimately, heated to correct temperature, cooled, and filter-pressed. The clarified oil is thereby removed from the adsorbent and then conveyed to storage. Fuller's earth has been in common use for this purpose. It must be reactivated from time to time by heating and eventually must be discarded. Bauxite has replaced fuller's earth in many operations and is preferred since it can be revived almost indefinitely without loss of adsorptive ability. Similar methods are used in the treatment of vegetable oils.

The purification of water has become a problem of steadily growing importance. Growing populations and increased industrial demands have exhausted many sources and the use of river water, involving many problems of pollution, has become common. Efficient filtration is a necessity, and this is accomplished by the use of sand beds that remove suspended matter. Crushed and sized anthracite has been substituted for sand in some installations. Adsorption on the surface of the anthracite with removal of taste or odor is probable. Fuller's earth or activated clays may be added to the water to effect the same purpose. Water softening with the use of glauconite or the manufactured zeolites is concerned primarily with base exchange and the removal of calcium from the water. At the same time some adsorptive forces are active.

In the sugar industry diatomaceous earth is used as a filtering medium. Whether the process is entirely mechanical or some adsorptive phenomena are present is debatable. Diatomaceous earth possesses a most intricate microscopic structure and is an extraordinarily efficient filtering medium. Sugar solutions are decolorized by percolation through fuller's earth or bauxite, the choice being dependent upon the pH of the liquid. Many special applications of adsorbents exist, such as the decolorization of organic solvents and dry-cleaning fluids, the removal of nickel from hydrogenated oils, the recovery of glycerin from lye in soap manufacturing, and many others.

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MINERAL PIGMENTS

The production of mineral pigments is one of the most ancient of industries, and their use by primitive people is well known. The mining of mineral paints may well have been the first mineral industry carried on by American Indians. Iron-ore mining operations in Missouri have disclosed extensive aboriginal workings extending to a depth of 20 ft and provided with extensive tunnels capable of accommodating standing workmen. Quantities of stone hammers have been found, and the size of the workings indicates that considerable tonnage was removed. Red and yellow oxides of iron were recovered; the same compounds that constitute the bulk of the modern mineral pigment industry. Apparently these paints were transported over long distances and formed an important item in early trade.

Modern industry developed to commercial stature in Pennsylvania, due in part to the presence of limonitic iron ores in relative abundance in the eastern part of the state, and in part to the presence of beds of ocher extending from Easton in a southwesterly direction toward Reading. Considerable pigment was recovered from the washing of iron ore, and some operations were conducted to produce both products. The mining of paint ores in the Lehigh Valley was active by 1850, and shortly after the Civil War the establishment of mills expanded production and led to the development of new products and eventually the manufacture of synthetic pigments. Geographical location in the center of a highly industrialized area contributed to the successful development and permanence of the industry. Pennsylvania continues to maintain its leadership as a producer. Production is recorded also in New Jersey, Illinois, Virginia, Ohio, and Georgia.

Some minerals exhibit desirable color and other properties, making them useful for the pigmentation of paints, mortar, concrete, plaster, brick, and other materials. In addition to acting as a pigment they may act as fillers, and there is some overlap in the fields of mineral pigments and mineral fillers, some commodities serving both industries. Natural pigments have some economic factors in their favor: wide geographic distribution, ease of preparation, relatively low costs of production, chemical stability, and permanence in use, so that they continue to supply the basis of a small but useful industry. When used in paints pigments act as a filler and supply body and opacity as well as color. Natural mineral pigments are prepared for the market by the comparatively simple processes of washing, grinding, blending, and calcining. Any one or all of these operations may be applied to a single pigment. The greatest skill in the industry is concerned with the preparation of certain shades of color and the manufacture of a nonvarying, uniform product. The development of the synthetic pigment business and the use of by-product materials have introduced competition with the products of nature and are exerting a growing influence on the economic position of the mined minerals.

The discussion here will be limited to the natural minerals and their immediate competitors. It will not include the very important mineral pigments manufactured from lead, zinc, titanium, chromium, cobalt, iron, and other metals.

Iron—Nature's Most Useful Pigment. Iron is one of the most abundant elements and is found universally distributed in many forms and in many minerals. Compounds of iron are the most important natural pigments. The iron pigments display many desirable characteristics, including good covering power, light fastness, stability, and high index of refraction. Ferric oxides are characteristically red, as is shown by the universal red coloration accompanying the mining and utilization of hematite (Fe_2O_3), the most valuable ore of iron. Hydrated ferric oxides display various shades of yellow, depending upon the iron content of the material and the nature of the associated impurities. Ocher is a typical pigment of this nature. The presence of small amounts of manganese oxide (black) or carbon as organic matter in the hydrated iron oxides masks the original yellow and produces various shades of brown, of which umber is a common example. Magnetite (Fe_3O_4) is one of the few black minerals that grinds to a black powder. The use of the natural mineral as a pigment has not been significant. A similar product, precipitated magnetic black, is manufactured. Ferrous compounds are commonly green. Since they are not stable, being subject to oxidation with color change, they have not become important as pigments. They are employed incidentally in some green rocks used for ornamental purposes. The mineral pigments vary from earth colors of low intensity and great dilution of iron content to almost pure iron compounds with high tinting strength and correspondingly greater value.

Some connection has existed between the production of pigments and the mining of iron ores, although the production of colors is not carried on appreciably as a by-product of mining. In the early development of the industry iron mining was common in Pennsylvania, New York, and other eastern states. There were a large number of small producers of hematite, limonite or bog ore, and carbonate ore. Some of these mines were small producers of pigments. The development of the Lake Superior iron ores resulted in the cessation of operations of these eastern producers. The knowledge of the location of these deposits and their possibilities as producers of pigments contributed to the development of the color industry after their importance as ore producers was past.

Many iron compounds may be changed in color by calcination, with its accompanying dehydration and oxidation. The end product is Fe_2O_3 , a stable red oxide, and whatever impurities were associated with the original material. The yellow hydrated oxides may be calcined red. The gray carbonate, found in Carbon County, Pa., calcines to a brilliant red. Copperas (ferrous sulfate) available as a by-product of the steel industry, breaks down under calcination to residual red oxide. Pigments produced by calcination possess the advantage of fine particle size, contributing to tinting strength and covering power, and ease of grinding.

Classification of Pigments by Color. The classification of pigments by color is also somewhat indefinite, because many colors lie between the standard shades and may be classed with either of two groups. The nomenclature is somewhat confusing in that the same name is often used indiscriminately by the trade to apply to several distinct materials, both natural and artificial. The more impor-

tant colors are briefly defined below, but more extended descriptions of the chief natural earth pigments are also given later in this discussion.

Mineral Blacks. Heavy black slate or shale is used to some extent in paint for buildings, but is used chiefly as black filler for ironwork. It is often toned with other blacks (carbon or lampblack) that are not so heavy, but the consumption is small because of its destructive action on paint mills and because its tinctorial power is not high. Quite as satisfactory results are obtained by the use of fine silica tinted with lampblack, and at less cost. These blacks (mineral black, slate black, oil black, black chalk, etc.) are perhaps more important abroad than in this country and are found in abundance in Bavaria, Spain, Italy, and elsewhere.

Coal. Powdered coal of various kinds is also used in some paints. It generally contains sulfur compounds, which are exceedingly harmful to metal and which prevent its being mixed with lead pigments. The semianthracites of Sullivan County, Pa., grind to a black useful for certain purposes.

Manganese Ores. Pyrolusite and hausmannite (natural oxides of manganese) are sometimes powdered for use as pigments, but their most important application in the paint trade is as driers in the preparation of boiled linseed oil.

Graphite, or crystalline carbon, both natural and artificial, is an important paint pigment. Its extreme lightness requires that it be diluted with a heavier base, often silica, to give it "tooth" and prevent it from being spread too thin. If used alone, 1 gal of graphite paint will cover from 1,000 to 1,600 sq ft of surface, or two or three times as much as most other pigments. Few graphite paints contain as much as 60 per cent graphite, since, in addition to its spreading too thin, it is also a slow drier.

Asphaltum. Asphalts and bitumens are frequently used in the paint trade, although they are not strictly pigments.

Greens. *Green earth, terre verte, green ocher, celadon green, verona green,* etc., is the only important natural mineral green. It varies considerably in composition, but consists principally of ferrous silicate mixed with silicates of the alkalies and magnesium. It varies in color from pale bluish green through apple green to olive green or greenish black. While it is a durable, inert pigment, it does not have much body and is low in color intensity. Owing to its high absorbent capacity for certain aniline colors, it is used extensively as a base for cheap lakes.

Green earth occurs chiefly in Bohemia and Italy, as a decomposition product of basaltic tuffs. It is prepared for market by grinding, washing, and drying or by heating, quenching in dilute hydrochloric acid, regrinding, washing, and drying. The acid treatment improves the color.

Green rocks are employed to produce granules for roofing and stucco dash. Altered volcanics, commonly called "greenstones," slate, serpentine, and epidote sandstone have been used. Preparation is simple, consisting of crushing and screening to the desired size.

Blues. There are no natural mineral blues now in use in quantity. Lapis lazuli has been used as an artist's pigment and production in India is said to have been large at one time. It has been replaced by its synthetic equivalent, ultramarine. Azurite, a blue basic copper carbonate, is not stable and tends to change

to malachite, the green carbonate. It has been suggested that the green skies of some of the most valuable old Italian painting is due to the use of azurite that has altered during the passage of time.

Ultramarine is the most important blue pigment. It has the same composition as the mineral lapis lazuli. It is of indefinite and varying composition, but is considered as a double silicate of sodium and aluminum, containing a little sulfur. The formula $\text{Na}_2\text{Al}_3\text{SiO}_4 \cdot \text{Na}_2\text{S}$ has been assigned to it, but the common blue variety is believed to vary from a soda ultramarine, poor in silica $[4(\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8) \cdot \text{Na}_2\text{S}_4]$, to a modification high in silica $[2(\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10}) \cdot \text{Na}_2\text{S}_4]$.

Yellow, violet, red, and green varieties have been produced, the green variety being an intermediate product in the manufacture of blue ultramarine by one method. None of these other colors, except green, have any commercial importance, since they have little tinctorial power and are too expensive.

Ultramarine is made from a mixture of kaolin or china clay, soda ash (sodium carbonate) or glauber salt (sodium sulfate), carbon (charcoal, lampblack, etc.), sulfur, and sometimes diatomaceous earth or other siliceous matter.

Prussian blue, *berlin blue*, *chinese blue*, *turnbull's blue*, etc., belong to the group of *iron blues* or *ferrocyanide blues*. They consist essentially of iron ferrocyanides.

Cobalt produces the smalt blues, extensively used in the coloring of glass, decoration of porcelain, and other ceramic products.

Whites. No natural white minerals are of value as white pigments since they are not sufficiently opaque when mixed with oil. However, a number of ground minerals border on this field because they are useful as fillers or inert extenders. Among them may be listed clay, chalk, whiting, ground limestone and marble, talc, tremolite, gypsum, barytes, and others.

Mineral Reds. Most of the mineral reds derive their color from the presence of varying amounts of ferric oxide (Fe_2O_3), the mineral hematite. This may be present in relatively small percentages, as in the red slates and shales, or it may constitute as much as 90 per cent or more of the material, as in spanish red. The red oxide may occur naturally or it may be produced by heating hydrous iron oxide pigments, such as yellow ochers, to a sufficiently high temperature to drive off the water of composition.

Persian red or *crimson oxide* (the original indian red) contains 65 to 70 per cent Fe_2O_3 and comes from Ormuz Island in the Persian Gulf.

Spanish red is a nearly pure soft-red hematite, usually containing 80 to 90 per cent Fe_2O_3 .

Bole, *ruddle*, or *reddle* is a ferruginous, nonplastic red, yellow, or brown clay, usually containing 5 to 15 per cent Fe_2O_3 , used locally in India.

Purple oxide or *indian red* (natural) approximates spanish or persian red in composition, and is used straight as a cheap indian red or as an adulterant in true indian red.

Canadian red is a calcined limonite iron ore very high in ferric oxide (up to 98 per cent) Fe_2O_3 .

Red slates and *shales* (as well as yellow and black types) are low in coloring power and are ground and used as red pigments in linoleum and oilcloth, in mortar colors, in cheap paints for priming coats, etc.

Metallic paints are iron oxide pigments that are higher in the oxide content than the ochers. "Metallic paints," as marketed, usually contain from 33 to 64 per cent Fe_2O_3 . They are made (1) by grinding together a mixture of ocher and limonite iron ore and burning to form a red product rich in iron; or (2) by calcining and grinding a natural iron carbonate (siderite) paint ore found only in the Lehigh Gap district of Pennsylvania or grinding selected hematite.

Burnt ocher is a red pigment made by calcining yellow ocher at a high heat, thus converting the yellow hydrated iron oxide (limonite) to the red ferric oxide (hematite).

Red ocher is a natural pigment resembling burnt ocher.

Indian red, as the term is now used, is made by roasting copperas (iron sulfate) crystals, produced as a by-product from pickling liquors in wire or galvanizing mills. It is a very high-grade red pigment.

Colcothar, *rouge*, and *crocus* are similar to indian red in composition and method of manufacture, but are used for other purposes.

Red oxide or *oxide of iron*, as the terms are generally understood, is made in the same manner as indian red, but is lighter in shade. This term is also used rather loosely to apply to various types of natural red pigments high in ferric oxide.

Tuscan red is a shade of indian red made by toning up the color of a low grade of that pigment with a red coal-tar dye (alizarine lake).

Hematite paint is made by grinding a natural, more or less pure, and usually soft, hematite iron ore (see "Spanish red").

Venetian Red. Venetian reds are manufactured by the neutralization of pickling liquors from steel mills, containing ferrous sulfate in solution, with lime and calcination of the mixture. The pigment formed by the reactions incident to calcination is a mixture of red iron oxide and calcium sulfate. The term is used loosely and includes letdown reds produced by grinding hematite, or other red oxide with calcium sulfate (gypsum) to produce a mechanical mixture similar in composition to the product of calcination.

Yellows. *Yellow ocher* is the only important natural mineral yellow, and has been used since prehistoric times. It is known by many names, including mineral yellow, permanent yellow, stone yellow, roman ocher, roman earth, oxford ocher, chinese yellow, golden ocher, etc. It consists essentially of a mixture of clay, siliceous matter, and hydrated iron oxide (limonite), but may contain various materials as impurities. The best varieties vary in color from a lemon yellow to a golden yellow, but it grades into a yellow-brown (sienna) and may be grayish, due to impurities. The iron oxide content varies from 15 to 30 per cent or more.

Browns. *Sienna*, *italian earth*, *terra di sienna*, is a high-grade natural yellow-brown earth pigment consisting of a mixture of hydrous iron oxides and clays in varying proportions, with or without siliceous matter. It may contain a little manganese dioxide. It grades into ocher with decreasing iron oxide content and into umber with increasing manganese oxide content. It usually is higher in iron oxide than ocher (often 60 to 80 per cent) and therefore stronger and richer in color. The color varies from pure brown to reddish brown.

Burnt sienna, made by calcining raw sienna, varies in color from a pure brown to a bright red.

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Umber, raw umber, turkey umber, terra ombra, consists of a mixture of clay, hydrous iron oxide, manganese oxides, organic matter, and sometimes siliceous matter. It usually contains from 7 to 14 per cent manganese dioxide and often 50 per cent ferric oxide. It is a darker shade of brown than sienna.

Burnt umbers, velvet browns, chestnut browns, made by calcining umbers, have deeper and richer shades than the raw earths.

Vandyke brown, cassel brown, cassel earth, rubens brown are terms applied more or less indiscriminately to pigments composed of clay, iron oxides, decomposed wood, peat, lignite, and other organic matter. These pigments are obtained from bog earth, peat, or lignite deposits and are essentially mixtures of clay or ocher with varying proportions of bituminous matter. Certain shades of siennas or umbers are sometimes called vandyke browns. Imitation vandyke browns are made artificially from charred organic substances, such as bark, cork cuttings, and bone dust. Mixtures of lampblack, yellow ocher, and iron oxide are also sold as vandyke brown.

The chief source of cassel brown has been Germany, and at one time imports to the United States valued at over 1 million dollars annually were secured from this source. Satisfactory material has been developed in Arkansas and North Dakota so that imports are no longer important. Most of the production is sold as vandyke brown and is consumed as a paper stain.

Cologne earth is a bituminous (lignitic) vandyke brown that has been gently roasted, making the color darker and more permanent.

Cappagh brown, euchrome, mineral brown is a highly ferruginous, manganiiferous earth found at Cappagh mine, County Cork, Ireland. It is redder than raw umber but similar in composition. When calcined at 100°C, it changes to a rich reddish-brown color resembling burnt sienna and caledonian brown.

Caledonian brown is a raw earth pigment resembling burnt sienna in color. It contains hydrous oxides of iron and manganese. When calcined, it becomes a brownish black.

Metallic brown or mineral brown is made by calcining an impure hydrous iron oxide (limonite iron ore). It usually contains from 40 to 75 per cent ferric oxide (average 50 per cent). It is of variable color but resembles burnt sienna.

Miscellaneous Pigments. *Color lakes or lake pigments* are composed of a coloring principle absorbed by or precipitated on an inert and insoluble base. The term "color lake" originally applied only to those pigments produced by fixing the coloring principles on a transparent base, such as aluminum hydroxide. Now the term includes all pigments produced by fixing a dye on an inert base.

The base materials are almost invariably inorganic and generally white or transparent. Many bases are used, among which are the following: aluminum hydroxide, alumina, blanc fixe, "soft" silica, lead sulfate, lithopone, ground barite, gypsum, whiting, china clay, precipitated chalk, barium carbonate, talc, diatomaceous earth, tripoli, clay, ochers, umbers, etc. The base should be inert, insoluble, easily pulverized to a very fine powder, and of such a color as not to affect adversely the color to be precipitated or fixed upon it. Bases should (1) have good covering power; (2) be easily worked; and (3) not be affected by light, alkalies, acids, etc.

The colors used may be natural (vegetable or animal origin) or artificial (chiefly coal-tar dyes). The color lakes are also generally grouped into classes, depending upon the method of fixing the color on the base; for example, coal-tar dyes precipitated by barium chloride, coal-tar dyes precipitated by tannin, etc.

Some of the more important natural lake colors are *rose pink*, *dutch pink*, *madder lake*, and *carmine*. The coal-tar colors are far too numerous even to mention here, but two of the best known are *scarlet lake* and *alizarine lake*.

Mortar Colors. Mortar colors are medium- or low-grade pigments used for tinting mortar, cement, and concrete; and the colors are usually the various shades of red, brown, purple, blue, and black. As marketed, most of the colors are blends or mixtures. A great variety of materials are used for this purpose, some of the most important being iron oxide, "blue billy" (residue left from roasting pyrite), ground slate and shale, and even culm from coal washeries.

Gray ocher is composed chiefly of clay, silica, and organic matter. It may contain a small amount of ferrous hydroxide, which sometimes imparts a slightly greenish color. It is used as a filler for cheap paint.

Cream ocher is a clay containing as low as 5 per cent hydrous iron oxide. It is used to some extent as a primer on wood, but is of little value.

White ocher is ordinary white clay.

Many other minerals and materials have been used from time to time in the past or are still used in small quantities at present, but most of them are too unimportant to be noted here.

Synthetics. There has been a growing trend toward the manufacture of high-grade synthetic compounds of great tinting strength to replace natural pigments. Synthetics now supply nearly one-half the tonnage and three-quarters the dollar value of the American industry. They are manufactured from such low-priced bases as scrap iron or ferrous sulfate solutions produced as a by-product in the pickling of steel. The iron is dissolved in sulfuric acid to produce ferrous sulfate and the solution is then oxidized by the introduction of air, precipitating hydrous iron oxide, yellow, which can be converted to the ferric or red form by calcination. The tinting strength of the synthetics may be 10 times or more that of the natural pigment. Less weight is required, transportation costs are smaller, and the uniformity of the product permits accurate proportioning. Since the synthetics are produced under technical control they can compete with the highest quality of natural materials imported from foreign sources. French ocher, once the standard yellow of the American market, has lost much of its importance.

Natural pigments supply bulk as well as color. In certain markets where the final product is sold at a higher price than that paid for the pigment there may be a profit in the resale of the pigment. At this date it seems probable that the natural pigments have stabilized their position in some industries where they enjoy a preference due to economy or desirable performance in use. New markets will doubtless be dominated by the more powerful synthetics.

The Recovery of Hydrous Iron Oxide as a By-product of Coal Mining. Iron is present in anthracite and bituminous coal in the form of the sulfide, which may be pyrite or marcasite, both represented by the formula FeS_2 . These minerals have been recovered in small tonnages to be used as a source of sulfur, as described

in the section dealing with that element. These minerals are not particularly stable and oxidize upon exposure to the atmosphere. As mine workings advance, the opportunity for oxidation increases and mine waters show increasing amounts of sulfuric acid and ferrous sulfate. The ferrous sulfate, being a soluble salt, is carried away by mine drainage. This solution is clear until some oxidation takes place, which occurs commonly in the tunnels near the exits to the surface and in the adjacent natural drainage to which the mine drainage leads. Hydrous iron oxides are precipitated in quantity. X-ray examination shows the material to be limonite ($\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). This material is a brilliant yellow and locally is called "sulfur mud." The collection of this material in a few favorable places has become the basis of a small mineral industry and has supplied a new material for mineral pigments.

In a few favorable localities the topography is such as to supply a natural settling basin in which mine waters have been confined long enough to permit the accumulation of thousands of tons of material. In some places recovery of the limonite has been made from areas after exhaustion of the coal had led to closing of the mine years before. In Pennsylvania, where pigment recovery is attempted, logs and rocks are placed in the discharge of mine waters pumped from the mine. These obstacles agitate the water and aerate the solution, introducing oxygen and thereby accelerating the precipitation of the iron oxide. Economical recovery can be attained only where there is a substantial tonnage within a few hundred feet of sufficient thickness to permit movement by ordinary shoveling. The percentage of the total iron content deposited in recoverable form is doubtless small. Much of the iron is deposited in thin films over miles of stream beds in unrecoverable form, producing the yellow bedded streams common in western Pennsylvania.

The yellow mud is shoveled from the stream, which may be diverted, or in some cases from the floor of the mine tunnel, with care to avoid contamination by soil or coal. The mud is dried in the sun and then trucked directly to the paint mill or to railroad cars for shipping to the mill. As shipped the material contains about 40 per cent moisture. Cars have been shipped analyzing 96 per cent hydrous iron oxides on a dry basis. Material under 80 per cent is not acceptable. The average price paid to the producer in the past has been around \$6 per ton. No record of production is known, but estimates indicate that some 20,000 tons have been recovered.

These yellow oxides have not been used directly as pigments to any great extent. Most of the material has been calcined in furnaces designed to maintain an oxydizing atmosphere. The calcined and dehydrated oxide is ground in buhr mills, rolls, Raymond mills, or other equipment. The final product is a beautiful red, possessing the assets of high-quality iron pigments.

The production of mineral pigments in the United States is shown in Table 1.

Imports. Foreign pigments occupy a preferred position in some industries, the preference being based on satisfactory and uniform performance in the past. Italian siennas, turkey and cyprus umbers, spanish and persian oxides, and some french ocher are imported in relatively small tonnages. It is expected that more settled conditions abroad will permit some expansion in this business. Careful preparation and the excellent inherent properties of color and tinting strength

TABLE 1. NATURAL MINERAL PIGMENTS AND MANUFACTURED IRON OXIDE PIGMENTS SOLD BY PRODUCERS IN THE UNITED STATES, 1947

	Short tons	Value
Mineral blacks.....	*	*
Precipitated magnetic blacks.....	*	*
Natural brown oxides.....	5,861	\$ 308,440
Vandyke brown.....	*	*
Pure browns (96% or better iron oxides).....	1,016	219,997
Natural red oxides.....	20,524	946,997
Pure red oxides (98% or better Fe_2O_3).....	17,331	3,481,083
Venetian reds.....	7,127	579,603
Pyrite cinder.....	1,682	110,863
Other red iron oxides.....	18,817	2,214,358
Natural yellow oxides (high Fe_2O_3).....	*	*
Pure yellows (85% or better Fe_2O_3).....	10,495	1,635,365
Others (low Fe_2O_3).....	9,130	213,133
Siennas:		
Burnt.....	940	141,943
Not burnt.....	1,441	201,493
Umbers:		
Burnt.....	3,051	322,688
Not burnt.....	671	61,443
Others.....	17,280	730,066
Total.....	115,367	\$11,167,161

* Included under Others.

TABLE 2. SELECTED MINERAL PIGMENTS IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1943 TO 1946

Pigment	1943		1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Iron oxide pigments:								
Natural.....	581	\$22,051	1,494	\$61,231	2,837	\$125,370	5,423	\$318,239
Synthetic.....	800	92,966	686	86,188	439	58,380	759	106,302
Ocher, crude and refined.....	78	1,810	4	221	784	36,608	167	6,528
Siennas, crude and refined.....							755	73,129
Umbre, crude and refined.....			1,172	31,599	1,989	57,281	3,134	95,815
Vandyke brown.....							101	10,432
	1,459	\$116,827	3,356	\$179,239	6,049	\$277,639	10,339	\$610,445

ensure these pigments of a share of the American market. Imports for recent years are shown in Table 2.

Prices. Finished mineral pigments are generally quoted in cents per pound in bags. Representative prices obtaining in 1950 follow. *Reds*: synthetic iron oxide, $5\frac{1}{4}$ to $9\frac{1}{4}$ cents per pound; persian gulf, $6\frac{3}{4}$ to 7; spanish oxide, $5\frac{1}{2}$ to $5\frac{3}{4}$; venetian, $3\frac{1}{2}$ to 5 depending upon percentage of iron oxides. *Brown*: synthetic iron, $12\frac{1}{2}$ cents per pound; raw sienna, 4 to 12; burnt sienna, $3\frac{3}{4}$ to $14\frac{3}{4}$; turkey type, $5\frac{3}{4}$ to $7\frac{3}{4}$; vandyke, $9\frac{3}{4}$ to 12. *Yellow*: american ocher, golden, $1\frac{1}{4}$ to $2\frac{3}{4}$ cents per pound.

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MONAZITE AND THORIUM MINERALS

Composition. Monazite is a phosphate of the rare elements, cerium, lanthanum, and didymium $[(\text{Ce}, \text{La}, \text{Di})\text{PO}_4]$. It nearly always contains thoria (ThO_2) as an impurity, up to nearly 20 per cent. It also usually contains some silica and frequently small amounts of erbium and ytterbium. Commercially, monazite is valuable at present chiefly for its thorium content, and the analyses in Table 1 represent typical commercial materials.

TABLE 1. ANALYSES OF MONAZITE

	1	2	3	4	5	6	7	8	9	10	11
ThO_2	1.43	2.32	6.49	18.60	10.05	6.49	10.22	8.65	10.29	8.38	5.03
Ce_2O_3	32.93	65.32 ^a	{ 31.38 30.88 }	16.30	32.14	31.28	31.90	61.73	{ 27.37 32.27 }	25.46	33.06
$(\text{La}, \text{Di}, \text{Yt})_2\text{O}_3$	25.54 ^b										
$(\text{La}, \text{Di})_2\text{O}_3$				34.70	25.99	30.88	28.46			35.52	30.35
P_2O_5	18.38	28.16	29.28	24.04	25.51	29.28	26.82	26.50	27.67	23.92	26.70
SiO_2	6.40	3.20	1.40	2.70	2.63	1.40	2.90	1.00	1.03	0.92	1.22
ZrO_2					0.60						
TiO_2	4.67	0.61									
Fe_2O_3	7.83				1.79		1.50	1.09	0.81	2.78	2.21
Al_2O_3	1.62				0.84		0.17	0.12	0.17	0.84	0.44
CaO	1.20				0.20		0.20	0.13	0.41	0.61	1.11 ^c
H_2O			0.20		0.92	0.20	0.46	0.45	0.20	1.28	0.59
Miscellaneous.....				1.10 ^d							
Total.....	100.00	99.61	99.63	97.44	100.67	99.53	100.63	99.67	100.22	99.71	100.71

^a Including ZrO_2 and BeO .

^b Including ZrO_2 , BeO , and Ta_2O_5 .

^c CaO , 0.90; MgO , 0.21.

^d $(\text{Yt}, \text{Er})_2\text{O}_3$.

1. Monazite sand from Burke, N.C.; not pure monazite. GLASER, C., *J. Am. Chem. Soc.*, Vol. 18, pp. 782-793, 1896.
2. Nearly pure monazite from Shelby, N.C., *idem*.
3. Sand from Brindletown district, Burke, N.C. PENFIELD, S. L., *Am. J. Sci.*, Third Series, Vol. 24, p. 252, 1882.
4. Amelia County, Va. PENFIELD, S. L., *idem*.
5. Monazite in large pieces from river bed; Southern Sierra dos Aymores, Espirito Santo, Brazil. FREISE, F., *Z. prakt. Geol.*, Vol. 18, pp. 123-124, 1910.
6. Brazilian monazite, analysis by F. H. Lee. GOTTSCHALK, A. L. M., *Mining Eng. World*, May 15, 1915.
7. Sand from Travancore, India. JOHNSTONE, S. J., *J. Chem. Ind.*, Vol. 33, pp. 55-59, 1914.
8. Isolated from a concentrate from Travancore, India. JOHNSTONE, S. J., *idem*.
9. Monazite pebble from Ratnapura, Ceylon. JOHNSTONE, S. J., *idem*.
10. Concentrated monazite from the Sempang Tin Co., Pahang, Malay Peninsula. *Imp. Inst. Bull.*, Vol. 4, pp. 301-309, 1906.
11. Forty pebbles from Moolyella, Western Australia. SIMPSON, E. S., *Bull.* 48, *Geol. Survey W. Australia*, 1913.

It should be noted that most of these analyses represent concentrated monazite or selected samples rather than monazite sand, and that they are considered to be of at least possible commercial importance. Some monazite contains so little thoria that it is of no present value. Brown* states that commercial monazite has the following average composition: ThO_2 , 5 to 10 per cent; Ce_2O_3 , 25 to 35 per cent; $(\text{La}_2\text{O}_3, \text{Pr}_2\text{O}_3, \text{Nd}_2\text{O}_3)$, 20 to 30 per cent; Yt_2O_3 , 1 to 3 per cent; P_2O_5 , 25 to 30 per cent; SiO_2 , 1 to 4 per cent.

Monazite sand as found may contain too low a percentage of thoria to be

* BROWN, J. COGGINS, Notes on Monazite, *Indian Ind. & Labour, Bull.* 3, 1921, pp. 17-34

marketable, yet when concentrated may yield a high-grade product. Thus, an Indian monazite sand may contain, as found, as high as 46 per cent monazite. When partially concentrated to 62 per cent monazite (with 26 per cent ilmenite and 11 per cent zircon), it may yield 5 to 6 per cent thoria; and, when concentrated to 90 per cent monazite, it contains about 9 per cent thoria.

In addition to monazite, the minerals *thorite*, *thorianite*, and *auerlite* are of some interest as a source of thoria.

Thorite, a silicate of thorium (ThSiO_4), contains, theoretically, 81.5 per cent ThO_2 , but, as found, the thoria content ranges from 49 to 74 per cent. It is generally dark brown to black in color and may also be orange, with glassy to resinous luster, and shell-like fracture. It has a hardness of 4.5 to 5 and a specific gravity of 4.4 to 5.2. It usually occurs in irregular masses in pegmatite. It has been found in small quantities in Norway and Ceylon and small shipments have been made from these deposits.

Thorianite is an isomorphous mixture of thoria (ThO_2) with uraninite (UO_2). The formula is sometimes given as $\text{ThO}_2 \cdot \text{U}_3\text{O}_8$. It contains from 59 to 93 per cent ThO_2 , also UO_2 , and often Ce_2O_3 and ZrO_2 . It is a black mineral, specific gravity 9.3, occurring as grains in placer deposits and disseminated in pegmatites. It was first discovered in 1904 in the refuse from gem washings near Belangoda, Ceylon, and between 1904 and 1911 from 150 to over 20,000 lb per year were produced, valued at from \$1 to \$7 per pound. In 1919 the price was \$7 per pound (or \$12 per pound of contained thoria). It has been reported also in the United States, Madagascar, and Russia, but Ceylon alone has produced.

Auerlite, a silicate of thorium, is a dull yellowish-white to reddish mineral closely related to thorite, found at the Freeman zircon mines near Zirconia, Henderson County, N.C. Several pounds were produced and it is stated that further exploration might develop a deposit of commercial interest.

General Description. Monazite is generally found as small, heavy, brownish or yellowish resinous grains in sand or disseminated in rock; less often in angular masses.

Physical Properties. *Hardness*, 5 to 5.5. *Specific gravity*, 4.9 to 5.3. *Melting point*, high. *Index of refraction*, 1.786 to 1.837. *Color*, reddish brown, yellow, reddish, and brownish gray. *Streak*, white. *Luster*, resinous. *Cleavage*, perfect basal. *Fracture*, conchoidal. *Transparency*, translucent to opaque. *Tenacity*, brittle.

Occurrence. Monazite is widely distributed in igneous rocks and is found infrequently in gneisses intruded by pegmatites. Concentrations in place have never been found that would permit systematic mining. The nearest approach to such a condition are the masses of monazite encountered in the mining of Norwegian pegmatites for feldspar. The monazite is saved, but the tonnage accumulated has never been of commercial significance. Destruction of monazite-bearing rocks by the forces of nature has liberated the mineral. Because of its chemical stability it is not altered easily, and due to its high specific gravity it tends to accumulate with other heavy minerals. Therefore, it is an ideal placer mineral. It is concentrated by stream and wave action, and commercial production has been obtained from stream gravels and beach sands. Marine placers

have been productive due to the secondary concentration effected by the waves on material already concentrated by the streams that have transported the monazite from its original source.

United States. Monazite was discovered in North Carolina in 1879. Commercial production began about 1886, and further exploration disclosed the presence of monazite in a belt extending southwesterly from Wilkesboro, N.C., to Anderson, S.C. The monazite was found in narrow gravel concentration. Much of the production until 1901 was done by local farmers working in idle time. Thereafter German interests installed modern concentrating equipment and shipped their output to Germany. Interest at the time was centered entirely in the use of thorium in the incandescent-mantle industry.

The productive history of the Carolina industry as given by Pratt⁸ is presented in Table 2.

TABLE 2. PRODUCTION OF MONAZITE IN THE UNITED STATES, 1893 TO 1911

Year			North Carolina	
	Pounds	Value	Pounds	Value
1893	130,000	\$ 7,600	130,000	\$ 7,600
1894	546,855	39,193	546,855	36,193
1895	1,573,000	131,150	1,573,000	137,150
1896	30,000	1,500	30,000	1,500
1897	44,000	1,980	44,000	1,980
1898	250,776	13,542	250,776	13,542
1899	350,000	20,000	350,000	20,000
1900	908,000	48,805	908,000	48,805
1901	748,736	59,262	748,736	59,262
1902	802,000	64,160	802,000	64,160
1903	862,000	64,630	773,000	58,694
1904	744,999	84,838	685,999	79,438
1905	1,344,418	162,308	894,368	107,324
1906	846,175	152,312	697,275	125,510
1907	547,948	65,754	456,863	34,824
1908	422,646	50,718	310,196	37,224
1909	541,931	65,032	391,068	46,928
1910	99,301	12,006	83,454	10,104
1911-1915	0	0	0	0

Monazite has been produced also in small amounts in Idaho, Colorado, and Florida. In 1896 Brazil entered the world's markets as a major source of monazite. The effect of this move is shown in Table 2 in the decline in American production for that year and 1897. Brazil dominated the world's markets from 1898 and Brazilian output reached the record figure of 7,121 tons in 1907.

Brazil. Most of the monazite produced in Brazil has been derived from the coastal sands in the states of Bahia and Espirito Santa. Beach deposits reserved by the government have been the principal source of the mineral. In addition

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there are beach deposits lying behind the government reservations and inland deposits. Difficulty in determining the boundaries of government holdings has interfered with the development of some adjacent properties. Lack of transportation has prevented the working of many of the inland deposits.

India. Monazite sand with a high thorium content was discovered in India in 1909. The sand is found in the state of Travancore along the seacoast. Four major deposits are known; the highest grade, reported to contain over 50 per cent monazite, is located north of Cape Comorin. Abundance of low-priced labor has permitted profitable exploitation, and during recent years India has become the chief supplier of the United States.

Ceylon and the Netherlands East Indies are producers of some importance. Imports in the United States and their source are shown in Table 3.

TABLE 3. THORIUM ORE, CONCENTRATES, AND COMPOUNDS IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1936 TO 1945^a

Year	Monazite sand and other thorium ore and concentrates					Thorium compounds	
	Short tons from				Value	Pounds ^d	Value
	Brazil	India ^b	Other countries ^c	Total			
1936	119	488	607	\$25,324	4,411	\$5,578
1937	.....	336	...	336	13,579	
1938	110	346	...	456	18,210		
1939	54	1,336	170	1,560	52,016		
1940	201	2,766	...	2,967	99,827		
1941	747	2,763	...	3,510	107,306		
1942	1,346	3,052	...	4,398	175,483		
1943	1,911	3,069	...	4,980	220,480		
1944	384	...	384	13,782	25	5
1945	437	112	...	549	19,581		

^a Data for 1946 not available for publication.

^b Includes following quantities originating in India but reported by U.S. Department of Commerce from United Kingdom: 1936, 29 tons; 1938, 7 tons; 1943, 36 tons.

^c 1936: Ceylon; 1939: Netherlands East Indies.

^d 1936: France (4,410) and Germany (1); 1945: Canada.

Mining and Preparation. Since production has been restricted to placer operations, methods similar to those employed in gold placers have been used. The monazite is concentrated along with other heavy minerals by panning, sluicing, or hydraulicking. The comparatively small size of the industry has not encouraged the employment of dredges. The concentrate is purified by electromagnetic or electrostatic treatment.

Utilization. The most important use of monazite was in the manufacture of thorium nitrate used in the preparation of incandescent mantles, extensively used

for illumination before electricity displaced gas as a lighting medium. These mantles consisted of about 99 per cent thoria and 1 per cent ceria. They are still manufactured for use with gasoline and kerosene and are valuable in areas where other sources of light are not available. A portion of the excess cerium has been employed in the manufacture of a pyrophoric alloy, known as "misch metal." This is a mixture of about 70 per cent iron and 30 per cent cerium and other rare metals. When scratched with steel, sparks are produced that will ignite inflammable gases. It is a common component of cigarette lighters and is sold under the name "flint." Monazite is a source of mesothorium, a radioactive element having properties similar to radium and substituted for it in luminous paints on watch dials. It is also used as a source of the rare elements lanthanum, neodymium, didymium, and praseodymium.

Thorium is a potential source of a nuclear fuel since it can be transmuted to uranium 233. At an early stage, therefore, it was part of the atomic energy program and data relative to its possibilities were restricted. However, it was decided to concentrate efforts on uranium and the government now (1950) neither buys nor encourages the production of monazite. It is reported that India has banned exports of monazite because of possible strategic importance.

Prices. In 1950 monazite sand, 60 per cent rare minerals, was quoted at 16 cents per lb, fob Atlantic ports.

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NEPHELINE AND NEPHELINE SYENITE

General Description. Nepheline (or nephelite) is a sodium aluminum silicate that, in the natural mineral, always contains potash. Chemically it somewhat resembles the soda feldspar, albite, but has a much lower silica-alkali ratio. Nepheline syenite is a rock of which nepheline is an important and essential constituent. Nepheline syenite is the only form in which this mineral occurs or is now used on this continent, but the pure mineral, either natural or artificial, may be produced and used. Both the rock and the mineral, therefore, will be discussed here.

Composition. An artificially prepared nepheline is a pure sodium aluminum silicate with the formula NaAlSiO_4 or $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$. The natural nepheline, containing potash, has been given the formula $\text{K}_2\text{Na}_6\text{Al}_8\text{Si}_9\text{O}_{34}$ or $\text{K}_2\text{O} \cdot 3\text{Na}_2\text{O} \cdot 4\text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2$. It has been suggested that natural nepheline may be a molecular combination of KAlSiO_4 or $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ and $\text{NaAlSi}_3\text{O}_8$ or $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$.⁸

Table 1 shows the relation in composition between nepheline, nepheline syenite, and certain feldspars.

TABLE 1

	1	2	3	4	5	6	7
SiO_2	42.25	44.1	59.30	48.92	64.7	68.7	69.0
Al_2O_3	35.92	33.2	24.70	31.69	18.4	19.5	18.0
Fe_2O_3.....	.....	.....	0.06	0.10	.....	.....	0.06
TiO_2.....	.....	.....	0.002	0.01	.....	.....	.....
CaO}.....	.....	.....	0.27	0.86	.....	.....	.....
MgO}.....	.....	.....	0.02	0.06	.....	.....	.....
Na_2O	21.83	15.1	9.91	13.70	.....	11.8	2.0
K_2O}.....	.....	7.6	5.10	4.06	16.9	.....	11.0
Loss on ignition.....	.....	.....	0.44	0.43	.....	.....	.....
	100.0	100.0	99.802	99.83	100.0	100.0	100.06

1. Theoretically pure artificial soda nepheline.

2. Theoretically pure natural soda-potash nepheline.

3. Blue Mountain (Canada) nepheline syenite; analysis quoted by C. J. Koenig, *The Use of Syenites in Semivitreous Ware, Ohio State Univ., Eng. Expt. Sta., Bull. 94, May, 1937.*

4. Bancroft, Ontario nepheline syenite; analysis quoted by G. A. Bole, *Nepheline Syenite. A Review of the Literature, Ceram. Age, November, 1939, pp. 135-137.*

5. Theoretically pure potash feldspar (orthoclase or microcline).

6. Theoretically pure soda feldspar (albite).

7. Average composition of typical feldspar used by glass industry.

Physical Properties. *Nepheline.* Hardness, 5.5 to 6. Specific gravity, 2.55 to 2.65. Fusibility, 3.5 in scale. Index of refraction, 1.538 to 1.542. Color, colorless, white, grayish, or yellowish; when massive also dark green, greenish or bluish gray, brownish red, and brick red. Streak, white. Luster, vitreous to greasy. Cleavage, (in crystals) good in one direction, imperfect in second direc-

tion. *Transparency*, transparent to opaque. *Tenacity*, brittle with subconchoidal fracture. It gelatinizes with acids.

Occurrence. Nepheline is rather widely distributed, geologically, as a constituent of soda-rich alkaline rocks that have formed from a magma too low in silica to permit the full development of albite feldspar. Hence, nepheline syenite never contains free silica except perhaps as a secondary mineral. Usually it is accompanied by albite and microcline feldspars with small amounts of muscovite and biotite mica, magnetite, and hornblende. Corundum may occur in minor amounts. Apatite is the major constituent of the Russian deposits. Pure nepheline has never been found in commercial quantities and very few deposits of nepheline syenite, amenable to beneficiation by present methods, have ever been found.

United States. Although many occurrences of mineralogical interest are known in this country, no workable commercial deposits capable of yielding high-grade products for the glass and ceramic trades have ever been developed. Grinding mills in New York, New Hampshire, and elsewhere have operated on rock brought in from Canada. Deposits of nepheline syenite near Beemerville, N.J., near Magnet Cove, Ark., and elsewhere have been tested and found not amenable to beneficiation to produce high-grade products, although they have been suggested as sources of roofing granules.

Canada. Nepheline syenites are widespread over two areas in central Ontario: the first and most important lies in Peterborough, Haliburton, and Hastings counties, and the second in Renfrew County and the Parry Sound area. In the former zone there are two belts; the more northerly, known as the Bancroft area, is characterized by a high nepheline content but spotty and erratic in occurrence. The southerly or Blue Mountain area consists of a ridge about 350 ft high by about 5¼ miles long in Methuen Township, Peterborough County, 26 miles northeast of Lakefield. In this mass one single block of rock containing about a million tons has been blocked out by diamond drilling. While relatively small tonnages have been produced from the Bancroft area the really important development has been at Blue Mountain by the American Nepheline Corp. and its subsidiary, Canadian Nepheline, Ltd. The average mineralogical composition of the rock, by volume is as follows:⁶

<i>Mineral</i>	<i>Volume Per Cent</i>
Albite.....	54
Microcline.....	20
Nepheline.....	22
Muscovite mica.....	2
Mafics (biotite, hastingsite, magnetite).....	2
Total.....	100

Other undeveloped deposits in Canada are reported near Port Coldwell on the northern shore of Lake Superior; in the Ice River district near Field, British Columbia; and at several other localities in Ontario and Quebec.

Russia. Exceedingly large deposits of aplite associated with nepheline and 5 to 20 per cent aegerite, magnetite, and titanomagnetite occur on the far-northern

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Murmansk coast of the Kola Peninsula near Khibinogorsk. These deposits are worked by Russia on a large scale to produce aplite for use as a fertilizer material with nepheline as a by-product, the separation being made by flotation. The nepheline product is reported to be used not only in glass and ceramics but also in portland cement and as a source of alumina for making aluminum.

Other Countries. In *India* nepheline syenite has been mined and used as a partial substitute for soda ash in glass. Deposits of nepheline syenite of possible commercial interest have been reported in *Korea* and in *Norway*.

Production. As noted before, there is no United States production of crude nepheline syenite. All crude ground in this country, nearly all of it at Rochester, N.Y., is imported from Canada. Table 2 shows the Canadian production and exports in recent years. Of the total exports, nearly all of which come to the United States, all but about 2 per cent is crude rock.

TABLE 2. CANADIAN PRODUCTION AND EXPORTS OF NEPHELINE SYENITE*

Year	Production		Exports	
	Short tons	Value	Short tons	Value
1940	20,510	\$117,849	23,812	\$111,357
1941	39,707	227,583	29,385	109,936
1942	42,206	246,893	32,840	89,520
1943	49,901	292,010	36,240	129,826
1944	47,625	217,989	35,310	123,905
1945	61,345	275,766	48,351	153,311
1946	61,261	229,198	51,839	168,895
1947	65,539	260,663	42,826†	135,895†

* *Mineral Trade Notes*, U.S. Bur. Mines, February, 1948, p. 31.

† 1947 exports are for 10 months only.

Mining and Milling. There is only one producing operation of any importance on this continent and that has recently been described in detail by Deeth and Koenig.⁴ The deposit is opened both by an open quarry, used in the four summer months, and by underground operations. Underground the ore is mined by shrinkage stoping methods, trammed electrically to the foot of a 300-ft inclined shaft (10-deg dip), hoisted, and dumped directly into mill bins.

Mills are operated at three points: (1) at the mine, where a coarse crushed, $\frac{3}{4}$ -in. material and a 24-mesh glass-grade product are made; (2) at Lakefield, Ontario, where 24-mesh and crushed rock are stored for shipment and where 200-mesh pottery grade is made; and (3) at Rochester, N.Y., where both glass and pottery grades are made from crushed rock. Crushed rock is shipped to Lakefield by truck and canal barge in summer, by truck in winter. Glass spar is shipped to Lakefield in covered tank trucks. Crushed rock is shipped by rail, via car ferry across Lake Ontario, to the Rochester, N.Y., mill.

Primary crushing is done with a jaw crusher to 3 in., followed by a cone crusher to $\frac{3}{4}$ inch, which is the product shipped to Rochester. At both the

Rochester and the Blue Mountain mills the rock is dried in direct-fired rotary driers, then crushed to 28 mesh in short head cone crushers, alone or with a Hardinge mill, in closed circuit with vibrating screens. The granular product is passed through high-intensity magnetic separators, which remove all the magnetite and even most of the feebly magnetic muscovite mica, reducing the iron content from about 1.5 per cent to about 0.07 per cent Fe_2O_3 . The total capacity of all plants is about 7,250 tons per month, of which about 56 per cent is of glass grade; 36 per cent, No. 1 pottery; and 8 per cent, No. 2 or B grade with about 0.6 per cent iron. Mill dust is collected at all points with cyclone and bag-type dust collectors. The dust collector product forms the B grade.

Wet milling with froth flotation was tried at Rochester, but it was unsuccessful and the process was discarded.

Specifications and Tests. There are no standard specifications for nepheline syenite but the following standards are adhered to by the producer. *Glass grade*: 0.05 to 0.07 per cent Fe_2O_3 ; uniform granular product, 28-mesh maximum grain size, low in fines. *No. 1 pottery grade*: same iron content as glass grade; uniform grind, 97.5 per cent —200 mesh, and not less than 95 per cent —325 mesh.

Markets and Prices. Glass-grade product is usually shipped in bulk in box-cars. Pottery grade may be shipped in bulk or in paper bags. In 1948 glass grade was quoted at \$14.25 a ton, bulk, Rochester, N.Y.; pottery grade at \$18.25 a ton, bulk; in bags, \$3 additional.

Utilization. The first and still the largest use for nepheline syenite in this country and in Canada is in glassmaking—particularly in container glass where a high-alumina content is desired. Its many advantages over feldspar include higher alumina content and lower fusion temperature, and is high in alkalis with high soda and low potash.

A large amount of research work has been done on the use of nepheline syenite in all types of whitewares, in both bodies and glazes, in enamels, as a ceramic bond in abrasive grinding wheels, in refractory cements, and in some types of heavy clay products. In all of these lines important commercial use has developed. Its valuable properties are attributed largely to the fact that it has a lower fusion point and greater fluxing action than feldspar. Its specific advantages in its many applications are too numerous to be listed here. The excellent annotated bibliography by Koenig⁷ lists the most important papers covering this subject.

Just before and during the Second World War much research was done in this country and in Canada to develop an economical process for the commercial extraction of alumina from nepheline syenite, but no production resulted. It is reported, however, that Russia, under her economic conditions, has done this successfully. It should be noted that the starting point there is more or less pure nepheline obtained as a by-product from their apatite milling operations. Russia is also reported to be using nepheline in making portland cement as well as in glass and ceramic wares.

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NITROGEN AND NITRATES

Adequate supplies of nitrogen are of primary importance in the economy of any country. Practically all explosives, until the advent of the atomic bomb, were nitrocompounds of one type or another. All wars have been marked by sudden increases in the productive capacity of explosive manufacturers. The problem of supply of raw materials frequently has been of the utmost strategic importance. The less spectacular utilization of explosives in mining and construction has become the engineer's most useful tool, without which few of the minerals described in this volume could be produced. A more fundamental use of nitrogen is in the maintenance of soil fertility and crop production, a problem whose seriousness can scarcely be exaggerated in countries faced with soil depletion and growing populations. Supplies of nitrogen were obtained first from organic sources, such as manures, fish scrap, kelp, cottonseed meal, and later from tankage and similar packing-house by-products. Such products are still used, although it is doubtful if they contribute as much as 15 per cent of the total supply of nitrogen. The production of organic nitrogen is now completely surpassed by the production of chemical nitrogen from mineral sources, fortunately present in almost inexhaustible amounts. The principal suppliers of nitrogen to the plant world have been the nitrifying bacteria and microorganisms in the soil. Their total contribution to the world's supply of this element exceeds all other sources.

SODIUM NITRATE (SODA NITER OR CHILE SALTPETER)

Composition. Sodium nitrate has the formula NaNO_3 : Na_2O , 36.5 per cent; NO_2 , 63.5 per cent; N, 16.47 per cent. Commercial 95 per cent crude Chile nitrate contains about 15.6 per cent nitrogen.

General Description. Sodium nitrate occurs as rather sectile granular masses or crusts, white, yellowish, or brownish in color, in arid regions or in caves protected from moisture; rarely in rhombohedral crystals of the same forms as those of calcite, but angles are nearly 90 deg (hence the term "cubic niter" sometimes used). It is somewhat deliquescent.

Physical Properties. *Hardness*, 1.5 to 2.0. *Specific gravity*, 2.1 to 2.3. *Melting point*, on heating deflagrates (less violently than niter) and melts at 1 in scale of fusibility. *Index of refraction*, 1.336 to 1.587. *Color*, colorless or white when pure; when found in nature, often bright lemon yellow, gray, or reddish brown. *Streak*, white. *Luster*, vitreous. *Cleavage*, rhombohedral, in crystals. *Fracture*, conchoidal. *Transparency*, transparent to nearly opaque. *Tenacity*, brittle. Very soluble in water, and solubility increases very greatly with increase of temperature, 100 parts of water dissolving about 70 parts sodium nitrate at 0°C, about 80 parts at 15°C, and 125 parts at 68°C. *Taste*, saline and cooling.

POTASSIUM NITRATE (NITER OR SALTPETER)

Composition. Potassium nitrate has the formula KNO_3 : K_2O , 46.5 per cent; NO_2 , 53.5 per cent; N, 13.86 per cent. Commercial 90 per cent saltpeter contains about 12.5 per cent nitrogen.

General Description. Potassium nitrate occurs naturally as thin, white, granular crusts or masses, or in minute needlelike crystals, and as a thin coating on earth, walls, and rocks. It is not altered on exposure.

Physical Properties. *Hardness*, 2. *Specific gravity*, 2.09 to 2.14. *Melting point*, on heating deflagrates violently and melts at 1 in scale of fusibility. *Index of refraction*, 1.334 to 1.506. *Color*, colorless, white, gray. *Streak*, white. *Luster*, vitreous. *Cleavage*, prismatic. *Fracture*, conchoidal. *Transparency*, translucent. *Tenacity*, brittle. Readily soluble in water. *Taste*, rather sharp, saline, and cooling.

NITROCALCITE

Composition. Nitrocalcite is calcium nitrate, $\text{Ca}(\text{NO}_3)_2 \cdot n\text{H}_2\text{O}$. Artificial calcium nitrate is $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$.

General Description. Nitrocalcite occurs in efflorescent, silky, white or gray tufts and masses, and has a sharp, bitter taste. It is very deliquescent before, but not after, being desiccated by heat. It occurs in cave deposits, as in Mammoth Cave, Ky.

Physical Properties. *Hardness*, very soft. *Specific gravity*, 1.9. *Melting point*, easily fusible. *Index of refraction*, 1.465 to 1.504. *Color*, colorless. *Streak*, white. *Luster*, silky. *Cleavage*, perfect in one direction. *Transparency*, transparent. *Tenacity*, brittle. Readily soluble in water. Very hygroscopic. *Taste*, sharp and bitter.

Occurrence and Methods of Recovery. The modes of occurrence of soda niter and niter are briefly noted in the descriptions of deposits given below. Nitrocalcite occurs as an efflorescence on the floors and walls of limestone caves and in their residual clay. During the War of 1812 and the Civil War, some of these clays were leached to recover the nitrates, but such deposits can never be sources of important quantities of nitrates and they are of no present commercial interest.

The source of practically all the world's production of natural nitrates is the sodium field of Chile. Potassium nitrate deposits in India and low-grade sodium nitrate deposits in Egypt together furnish perhaps 1 per cent of the total world production.

Chile. The sodium nitrate deposits of Chile are the largest deposits of natural nitrates known in the world. Chile enjoyed a practical monopoly in the nitrogen markets of the world until after 1900, when competitive sources became more important. The industry employed up to 50,000 workers, and an export tariff of around \$12 per ton supplied the largest single source of revenue to the country and at times paid up to 68 per cent of the total cost of government. The nitrate deposits are found in a narrow strip, over 400 miles long and varying from 5 to 40 miles in width. The area is essentially rainless, an important consideration in the preservation of this soluble mineral. Water for domestic use is piped from the Andes a distance of over 100 miles. The five major producing areas are served by the ports of Iquique, Antofagasta, Tocopilla, and Taltal.

The sodium nitrate exists as a cement around rock fragments. The richer layers are called "caliche." The geologic origin of this material is not understood and a number of theories, none probable, have been advanced. An analysis of typical material is as follows:

	<i>Per Cent</i>
Sodium nitrate.....	17.6
Sodium chloride.....	16.1
Sodium sulfate.....	6.5
Calcium sulfate.....	5.5
Magnesium sulfate.....	3.9
Potassium nitrate.....	1.3
Sodium borate.....	0.94
Potassium perchlorate.....	0.23
Sodium iodate.....	0.11
Sand, clay, and stone.....	47.82

The sodium nitrate content may run as high as 40 per cent. The minimum percentage that must be present to qualify as commercial material has declined steadily due to the application of new methods of recovery and treatment. Two methods of nitrate production are followed.

The Shanks Process. The Shanks process is the first to be established and is characterized by the employment of hand labor, primitive techniques, and inefficiency. Some two-thirds of the total recovery is still accounted for by this process, although 12 per cent nitrate is the minimum raw material that may be treated. Test pits are sunk to locate the caliche, and quality is determined by

inspection by an experienced worker. If satisfactory, mining is initiated, using hand methods for drilling, blasting, and loading rock into cars. Careful selection is necessary to maintain a grade above 12 per cent. The caliche is transported to extraction plants and crushed. Extraction of the nitrate is effected by the use of hot solutions. The solubility of sodium nitrate rises with a rise in temperature and at a rate much higher than sodium chloride, the principal soluble salt present. As the temperature increases the solution will precipitate sodium chloride and absorb more nitrate. Nitrates will crystallize from the solution after it is cooled and clarified, leaving rock fragments, insolubles, and most of the sodium chloride behind. The Shanks process produces a standard product running about 95.5 per cent sodium nitrate, equal to 15.7 per cent nitrogen. By further crystallization grades up to 98 per cent are prepared. Recovery varies from 65 to 70 per cent of the total present in the ores. Half of the operating cost is reported to be for fuel, 40 to 45 per cent for labor, and the remainder for power.

The Guggenheim Process. The Guggenheim process, developed in 1926, represents the application of modern methods of mining and mineral preparation to the problem of nitrate recovery. The deposit is proved by cross-sectional sampling and analysis. The overburden is removed by electric scrapers, the ore broken by drilling and blasting and moved by electric shovels to trains for transportation. The crushed caliche is dumped in 7,500-ton concrete leaching tanks. All operations are mechanized. The nitrate is extracted by solution with varying strengths of mother liquor at a temperature of 40°C. Crystallization is then carried out in stages under exact temperature control, near the freezing point. Heat recovery is effected wherever practical, with substantial savings. A product with a purity of up to 98.8 per cent is thereby produced. The advantages of this process are reduction in labor costs from 40 to 6 men per ton of nitrate, a great saving in fuel, and the utilization of much lower grade raw material, as low as 8 to 9 per cent. A final product is prepared by melting the nitrate in an oil-fired furnace. The melted nitrate is sprayed into a cooling chamber where it consolidates into beads about $\frac{1}{6}$ in. in diameter. This facilitates handling, bagging, and distribution.

Iodine and potassium nitrate are recovered as by-products of sodium nitrate production. Iodine is described in the section devoted to that element. Potassium nitrate is present in the caliche in amounts varying from traces to 17 per cent. Material containing 2 or 3 per cent is common. Potassium nitrate is recovered from the solutions after the removal of the sodium nitrate but before treatment for iodine. A number of methods are employed that are applicable to the Shanks or Guggenheim processes. The potassium nitrate may be recovered from the brine solution by fractional crystallization, by evaporation under controlled conditions, or by refrigeration. The product is marketed as a high-potash nitrate, usually containing about 68.8 per cent sodium nitrate and 28.9 per cent potassium nitrate. It was reported in 1947 that a process of solar evaporation was to be installed which would permit the recovery of large tonnages of potassium nitrate as well as other products from the solutions being discarded.

The reserves of caliche in Chile available for future use are not known with accuracy. They are believed to be adequate for many years.

Imports of nitrates in the United States are shown in Table 1.

NITROGEN AND NITRATES

TABLE 1. SODIUM NITRATE AND SODIUM POTASSIUM NITRATE IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1944 TO 1948
(Source, U.S. Bureau of Mines)

Year	Sodium nitrate		Sodium potassium nitrate	
	Short tons	Value	Short tons	Value
1944	713,004	\$15,346,426	9,407	\$278,534
1945	849,888	18,558,959		
1946	529,677	11,448,232	4,400	146,312
1947	556,525	15,153,889	2,500	64,968
1948	720,963	23,411,132		

Prices. In early 1950 Chilean nitrate was quoted at \$48.00 to 51.50 per ton at Atlantic ports.

Sources of Nitrogen. India. India has been a source of natural potassium nitrate from very early times. The industry reached its height from 1861 to 1865, when the average annual exports were over 30,000 tons. After the rise of the Chilean nitrate deposits the industry declined, and just prior to the First World War exports were only 13,000 to 14,000 tons per year. The nitrates of India are of organic origin. In hot countries the soil often becomes rich in niter in the vicinity of human habitations, especially where the population is congested and the climate is suitable for the action of nitrifying bacteria. Until 1850 such deposits in India were the chief source of saltpeter used in Europe and the United States for the manufacture of gunpowder.

Large deposits occur in the province of Eastern Punjab and are scattered over the districts of Hissar, Karnal, Rohtak, Gurgaon, and Lahore. The largest deposit are in Hissar and Karnal. Potassium and sodium nitrates are found in the soil as a white powder intimately mixed with the earth. In the village of Hansi (Hissar district) there is only one well to provide drinking water for 18,000 people. All other wells contain too many soluble salts to be potable. Near Kaithal large earthen mounds are rich in potassium nitrate. The ground is excavated with spades and transported to open concrete platforms, where it is leached with water. The water solution is run to a tank at a lower level and subjected to solar evaporation. The rainfall of the district is only 10 in. annually and does not interfere with such operations. The dried nitrate, valued at \$3 to \$4 per ton, is barreled and shipped to chemical plants. Part of the production is converted to potassium carbonate by treatment with wood ashes.

Egypt. Sodium nitrate apparently occurs in several localities in Egypt and is extracted by the natives for local use.

United States. Many small deposits are known to exist in the United States; most are located in the southwest. Abundance of rainfall in other areas has prohibited accumulation. Nitrates occur in caves, potassium nitrate being the principal mineral; in thin blankets of caliche in arid regions; and in playas, the dried crusts of shallow lakes in which soluble salts have collected. Commercial production in significant amount is believed impossible.

Other Sources of Nitrogen. The first major shift in the nitrogen supply was initiated in 1892 when the first by-product coke oven was installed at Solvay, N.Y. The ammonia recovered was utilized by the Solvay process in the manufacture of soda ash. The installation of by-product ovens spread rapidly in the steel industry, displacing the wasteful beehive ovens, and substantial amounts of ammonia were soon available. A more profound change was effected by the successful fixation of atmospheric nitrogen. This was begun about 1900 and received great stimulation from the soaring demands for nitrogen occasioned by the First World War. The atmosphere is the most universally distributed of all mineral resources and its utilization had many unexpected results. The Chilean monopoly was broken, the international pattern of resources was altered, and the ability to produce munitions for war was increased in countries that previously had been controlled by their access to nitrates from Chile. The shifts in the sources of nitrogen are illustrated in Table 2.²

TABLE 2. RELATIVE IMPORTANCE OF SOURCES OF CHEMICAL NITROGEN

Source	Per cent		
	1900	1913	1934
Chilean sodium nitrate.....	66.6	55.4	6.9
Coal.....	33.4	37.3	18.6
Total mineral.....	100.0	92.7	25.5
Air.....	00.0	7.3	74.5
Total, all sources.....	100.0	100.0	100.0

Nitrogen from Coal. Nitrogen from coal is recovered in the form of ammonia, which is an important constituent of the gases evolved during coking. The gaseous ammonia may be recovered by passage through water, converting it to aqua ammonia, or it may be neutralized with sulfuric acid, producing ammonium sulfate. Most ammonia is recovered as sulfate. The purity of the product has been improved by the use of a process in which the ammoniacal liquor is treated with lime to liberate the ammonia, which is driven off by the introduction of steam. The steam and ammonia are introduced in containers of sulfuric acid in which ammonium sulfate is precipitated. The crystals are removed, drained, washed, and dried. Before bagging they are treated at times with a reagent so that they will not coalesce to an unmanageable mass during storage. The average yield of ammonium sulfate per ton of coal charged to the oven is 20 lb. In 1946 ammonium sulfate, or its equivalent, was produced in 81 plants located in 21 states to the extent of 1,487,434,225 lb valued at \$18,024,763. Pennsylvania is the largest producer.

Nitrogen from the Atmosphere. The cyanamide process, developed by 1900, was the first process to be commercially significant. Coke and limestone are converted to calcium carbide, which is treated with nitrogen gas under slight pressure

at a temperature of 1000°C , forming calcium cyanamide according to the equation $\text{CaC}_2 + \text{N}_2 = \text{CaCN}_2 + \text{C}$. The cyanamide may be used directly as a fertilizer or it may be treated with water and steam under pressure to yield ammonia. No cyanamide is produced in the United States. Its manufacture at Niagara Falls, Canada, is still continued.

The passage of lightning through the air results in the formation of nitrogen oxides. Millions of tons of nitrogen are fixed annually by this natural method. It has been duplicated in the laboratory and in industry by the use of the electric arc, a method developed contemporaneously with the cyanamide process. The process requires large amounts of cheap electricity and has been used successfully only in Norway.

Processes for the Production of Ammonia. The nitrogen of the air may be combined with hydrogen from varied sources to produce ammonia. The ammonia subsequently may become a raw material for the preparation of other nitrogenous compounds. This has become the most important process for nitrogen recovery. The nitrogen is obtained in part by the distillation of liquid air; a greater amount is produced by the controlled combustion of coal in a forced current of air. The carbon of the coal oxidizes, removing the oxygen from the air. The discharge gas, called "producer gas," is essentially nitrogen. Hydrogen is produced by a number of methods. The largest contributor is water gas. This is produced by the passage of steam through a bed of incandescent carbon. The water forming the steam disassociates so that the water gas contains about 48 per cent hydrogen and 42 per cent carbon monoxide, with small amounts of carbon dioxide and nitrogen. This gas is treated further with steam and passed over an iron oxide catalyst to produce more hydrogen. The gas is then cleaned of steam and carbon dioxide, resulting in a final product containing from 92 to 94 per cent hydrogen. Hydrogen is also recovered from coke oven gas and prepared by the electrolysis of water. The last process is the most expensive but produces hydrogen of great purity.

The Haber-Bosch process was the product of research conducted in Germany; it was placed on a successful basis in 1913. Producer gas and water gas as sources of nitrogen and hydrogen are induced to combine to form ammonia at a pressure of around 200 atm and a temperature of 550°C , in the presence of iron oxide as a catalyst. The gases are recirculated after the recovery of ammonia, which amounts to about 8 per cent per pass through the converter. Changes have been made in this method by different operators in small details but without altering the basic principles involved.

The Claude process developed by the French engineer, Georges Claude, operates at higher pressures (900 to 1,000 atm) and higher temperatures (500 to 650°C). Ammonia recovery of 25 per cent is reported. Purification of the gases by liquefaction is stated to reduce costs. The plants are compact and have high capacity.

The Mont Cenis process is named for the company that built the first operating installation. It functions at 100 atm and a temperature of from 400 to 420°C . An iron cyanide catalyst has been used successfully. The gases are precleaned and fuel is saved by a system of heat exchangers. Since this is low pressure, operation costs of installation and operation are reduced.

The Casale Process. This Italian process operates at 500°C and about 600 atm pressure. Ammonia recovery of about 15 per cent is claimed per pass, and the gases are recirculated. A special catalyst of unusually long life is employed. This process was designed to use hydrogen produced by electrolysis of water. It is now used with hydrogen from other sources with success.

The Fauser process, also of Italian origin, operates at 500°C and 200 atm. Ammonia recovery of around 12.5 per cent is obtained. Electric energy is used to produce hydrogen and also to heat the converter under exact control. Recirculation of gases is kept at a minimum.

Nitrogen Engineering Corporation Process. The N.E.C. installations are reported to be a modification of the principles underlying the Haber-Bosch process. Exact details as to operating pressures and temperatures are not released. Ammonia conversion is reported at a high figure, 20 per cent or higher. Preheating of the gases and the use of long-life catalysts are said to reduce costs.

The American process was developed by the U.S. Department of Agriculture working through its fixed nitrogen laboratory. It operates at 300 atm and 475°C. Efficient catalysts consisting of iron, potassium, and aluminum oxides are employed. All installations are in the United States. The search for new and efficient catalysts continues.

In 1948 over 1 million short tons of anhydrous ammonia were produced in the United States in synthetic plants.

Atmospheric nitrogen in liquid form is available in increasing amounts in the United States as a by-product of oxygen production. It is available at a purity of 99.99 per cent. It is finding many uses in the prevention of oxidation, the removal of entrained oxygen, and the dilution of inflammable gases. Liquid nitrogen is also used to produce extremely low temperatures and for rapid cooling.

Utilization. Nitrogen compounds are essential to the fertilizer and explosive industries. A portion of the output is converted to nitric acid, which in turn is used to produce nitroglycerin, trinitrotoluol, nitrocellulose and many other nitro-bodies useful as explosives. Nitric acid is one of the most valuable chemical reagents and serves many industries of basic importance; it is used in the manufacture of dyes and pharmaceuticals and as a solvent. Ammonia, quoted in anhydrous form at \$76 per ton fob point of manufacture in 1950, is converted into a large number of ammonium salts for use in industry and for incorporation in fertilizers. The cheapness of ammonia and the ease with which it may be altered to produce other compounds has resulted in the manufacture of a large number of nitrogenous substances at prices lower than those obtaining in the past.

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OLIVINE

Composition. The olivine group of minerals is represented by the common formula R_2SiO_4 . It comprises fayalite (Fe_2SiO_4), olivine [$(Mg,Fe)_2SiO_4$], and forsterite (Mg_2SiO_4). Since olivine is the middle member of this series individual specimens may display considerable variation in composition. The typical composition of commercial material is MgO, 48 per cent; SiO_2 , 42 per cent; FeO, 8 per cent; Fe_2O_3 , 1 per cent. Small amounts of alumina, nickel, and chromium are often present.

General Description. Olivine is a greenish, transparent to translucent mineral occurring in granular aggregates, small disseminated grains, and in places in large masses of great tonnage.

Physical Properties. *Hardness*, 6.5 to 7. *Specific gravity*, 3.2 to 3.6. *Melting point*, 1413 to 1428°C. *Index of refraction*, 1.662 to 1.680. *Color*, various shades of green, also yellowish, brown, reddish, grayish, or colorless. *Streak*, white or yellowish. *Luster*, vitreous. *Cleavage*, pinacoidal; conchoidal fracture. *Transparency*, transparent to translucent. *Tenacity*, brittle.

Occurrence. Fayalite has been identified in granites and in some ores. Forsterite is found in metamorphic limestones. Neither mineral occurs in sufficient tonnage to excite interest. Olivine is a common constituent of basic rocks, such as basalt, gabbro and peridotite. Its concentration in large masses of fairly pure material produces a rock type known as "dunite." Industrial interest in olivine has been aroused by the discovery of dunite of high purity in areas of easy accessibility. On the Atlantic seaboard a belt of basic rocks extends from Canada to Georgia. In many places alteration has converted the original rocks to serpentine or soapstone. An area of unaltered material extending from North Carolina to Georgia has become a commercial source. The reserves available are estimated to be a matter of hundreds of millions of tons. The state of Washington has two outstanding dunite exposures. On the southeast corner of Cypress Island, about 80 miles northwest of Seattle, a dome called "Olivine Hill" shows a large exposure of dunite. Considerable alteration to serpentine is present. A large tonnage of commercial material is reported at tidewater. The Twin Sisters Mountain area, near Mount Baker, less than 100 miles from Seattle, is known to contain a large tonnage of dunite in an area some 10 miles long by 6 miles in breadth. The rock is conspicuous for its freshness, and while there is some weathering there is no conversion to serpentine or other secondary minerals.

Production. Because of favorable exposures and lack of overburden it has been possible to recover olivine from open-cut quarries. The material is broken from the mass by explosives and sorted by hand, which permits rejection of weathered or otherwise altered rock and the shipment of uniform material. Production since the origin of the industry is shown in the accompanying table.

PRODUCTION OF OLIVINE IN THE UNITED STATES

<i>Year</i>	<i>Short Tons</i>
1934	3,000
1935	6,000
1936	5,000
1937	4,000
1938	2,800
1939	3,000
1940	3,000
1941	4,828
1942	5,739
1943	5,415
1944	3,270
1945	Not available
1946	7,649
1947	10,838
1948	4,766

Prices. Olivine was quoted in 1950 fob North Carolina and Puget Sound, Wash., at \$6 to \$8 per ton for crude, \$18 for -200 mesh, and \$14 for material 20 mesh to dust.

Utilization. The first use was as a gem stone, and it is probable that many of the green stones loosely called "emeralds" in ancient times were olivine. The

gem variety is now called peridot, chrysolite, or evening emerald. Some of the finest gems have been obtained from St. John's Island in the Red Sea. The production of gem material has never been of economic importance. Olivine is not stable chemically as might be expected of a silicate. It is soluble in acids and therefore may be dissolved, liberating its constituents and permitting their conversion to forms useful in industry. Magnesium sulfate has been prepared by solution of the crushed olivine in sulfuric acid, removal of iron, and crystallization of the desired salt in commercial form. Similarly, it has been shown that the mineral can be converted to magnesia and magnesium metal. The most important industrial use has been in the manufacture of refractories of the forsterite type. Forsterite has a melting point of 1910°C or 3470°F, higher than that of many other materials employed as refractories. In the process of manufacture magnesia is added to the olivine in order to convert impurities, serpentine or enstatite, into forsterite. A brick of high forsterite content is thereby produced. Interest in this type of brick originated about 1928. They were in use by 1930. According to Birch and Harvey¹ these bricks show a pyrometric cone equivalent of about 38 and are superior to silica brick (cone 32). The volume stability is satisfactory, load-carrying ability excellent, spalling resistance comparable to the best basic brick, thermal conductivity lower than that of silica brick at high temperatures, and expansion rate uniform. These bricks have proved of value in the metallurgical industries and in portland cement and similar rotary kilns. Tests have shown that olivine sand may be used for sand blasting and as a foundry sand. The fusion of olivine with rock phosphate in the electric furnace produces a product containing 12 to 15 per cent magnesia and over 20 per cent available phosphorus pentoxide. This is finding increasing use in the fertilizer industry.

Foreign Deposits. Large tonnage deposits of olivine are reported to be present in Russia, Italy, Germany, Norway, New Caledonia, and New Zealand, and in Africa, associated with chromite. Norwegian olivine has been exported to Germany and England for processing.

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OPAL

Composition. Opal is hydrous silica ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$): H_2O , 1 to 21 per cent, but usually 3 to 13 per cent.

General Description. Opalescent or hydrous silica occurs in many forms, the best known of which are *precious opal*, *fire opal*, *opal jasper*, and *opalized wood*. Other forms are *hyalite*, which occurs in colorless, transparent, irregular masses resembling drops of melted glass; *geyserite* or *siliceous sinter*, a granular, compact, porous or stalactitic form deposited from hot water; *diatomaceous* or *infusorial earth*; and *tripoli*. Opalescence may be due to (1) fine cracks filled with material with an index of refraction slightly different from surrounding mass, (2) fine internal reflections from thin curved lamellae, or (3) uneven distribution of the water content. Some opaque opals may be made to show color and opalescence for a short time after immersion in water. This property is sometimes taken advantage of to sell worthless opals to tourists and other transient buyers.

Physical Properties. *Hardness*, 5.5 to 6.5. *Specific gravity*, 2.1 to 2.3. *Melting point*, high. *Index of refraction*, 1.406 to 1.46. *Color*, all colors and colorless; precious varieties show play of color. *Streak*, white. *Luster*, vitreous, greasy, pearly, or dull. *Cleavage*, none; conchoidal to irregular fracture. *Transparency*, transparent to opaque. *Tenacity*, brittle.

Occurrence. Opal usually results from the decomposition of silicate or siliceous rocks and is thus often found in cracks and cavities in igneous and sedimentary rocks. It also may be precipitated from hot solutions (geyserite), or be a replacement of wood (opalized wood), or result from the alteration of siliceous limestones or chert (tripoli).

Common opal is very widely distributed. Precious opal occurs at Queretaro, Zimapan, and elsewhere in Mexico; Czerwenitza, Hungary; Bula Creek, Queens-

land; Wilcannia and White Cliffs, *New South Wales*; Latah County, *Idaho*; Morrow County and Gem City, *Washington*; and Humboldt County, *Nevada*. Geyserite is abundant in Yellowstone National Park; also in *Iceland* and *New Zealand*.

Mining. The mining of opal is an irregular industry, erratically pursued, mostly by wandering prospectors. Excavations are shallow and generally restricted to following a high-grade streak. Months of labor may be invested with no profit, and then with luck a small fortune may be acquired in a few hours. The most productive area in the United States is located in Humboldt County, Nev., near the Oregon line. The opal is associated with petrified wood in beds of volcanic ash, which apparently were the source of the silica. Opal is not a stable mineral, and loss of the included water may destroy the beauty of the stone. Frequently the stone is buried for months or years after removal from the mine to allow slow drying and the production of a stable product. Similarly, care must be taken in the cutting and polishing of the stone to avoid heating and ruin of the material. The mining of opal has been a producer of substantial wealth only in Australia. In 1937 the all-time production of New South Wales was valued at £ 1,622,795. Lightning Ridge and White Cliffs have been spectacular producers. The total output of Queensland to 1937 was valued at £ 187,745. South Australia produced opal with a value of £ 160,158. The "black" opal of Australia with its deep shades of blue and green is a favorite in the United States and is imported in some quantity. Prices vary enormously. The "Pandora" opal and the "Flame Queen" found at Lightning Ridge are magnificent gems and are highly valued. Small specimens of attractive color may be purchased for a few dollars.

Uses. The employment of opal as a gem is the only important use. Common opal and opalized wood are cut for paperweights, book ends, and similar objects.

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OXYGEN

General Description. Oxygen, one of the commonest gases in nature, forms 21 per cent of the atmosphere by volume. The element has an atomic weight of 16.00, a melting point of -218.4°C , and a boiling point of -183.0°C . It is the most common element in the crust of the earth and is a constituent in most common minerals, particularly the oxides, carbonates, sulfates, and silicates. Water contains 88.9 per cent by weight. The supply may be said to be inexhaustible.

Production. Oxygen became a commercial mineral in 1895 due to the development of the von Linde process. This process consisted of the liquefaction of air from which nitrogen was distilled, leaving a liquid oxygen residue. The Claude process was introduced in 1902. These processes both operate at relatively high

pressures; they differ, however, in refrigeration techniques. The industrial use of oxygen grew rapidly and production increased in turn. In 1944 at the peak of war demand the United States produced 18,743,087,000 cu ft. This was high-purity material of 99 per cent grade. It was used mostly in cutting and welding metal and in medical practice.

The storage and distribution of such a fugitive material has been a problem. The usual custom has been to use a steel cylinder weighing 125 lb and containing 18 lb of gas at a pressure of 2,000 lb. The cylinder had to be returned for recharging and the two-way transportation of such a heavy container added to expense. Oxygen sold at prices ranging from \$50 to \$90 a ton. Lower prices for large quantities were reported, and in 1947, \$35 per ton for tank-car quantities was recorded.

The industrial significance of oxygen has been altered completely by the development of new processes for the production of low-purity, 95 per cent material. This can be produced at a far lower cost than the 99 per cent or better oxygen used in the past. Costs as yet are not fully established. A price well below \$10 per ton is assured. Estimates⁸ have indicated that operating costs varying from \$3.34 per ton for a plant with a capacity 100 tons per day to \$2.25 per ton for a plant with a capacity of 1,000 tons per day are possibilities. Power costs are a major item in the operation and may account for about two-thirds of the total expense. The production of cheap oxygen uses essentially the same processes employed in the past but with mechanical improvements reducing costs. Recent developments employ a low-pressure system operating substantially at atmospheric pressure. Liquid nitrogen is used to cool the air to a liquid, and lower pressures and temperatures are maintained in the heat exchangers.

The U.S. Bureau of Mines announced on Nov. 12, 1948, that the first oxygen plant for coal gasification had been completed and would be placed in operation within a few weeks. This plant, located at Louisiana, Mo., has a capacity of 1 ton per hr of 98 per cent oxygen. It is the Linde-Fränkl type of plant previously used in Germany. *Chemical and Engineering News* reported on May 31, 1948, that the Linde Air Products Co. would build a plant with a capacity of 360 tons of 95 per cent oxygen to supply the Belle, W.Va., plant of Du Pont and would erect another for the Wheeling Steel Corp. at Steubenville, Ohio. The same journal announced on Apr. 18, 1949, that a low-pressure type of plant would be constructed at Winshire, Tex., with a capacity of 175 tons per day of 90 to 95 per cent material by Dresser Industries, Inc. A number of other plants are in various stages of development.

The trend appears to be that large consumers will erect plants at the point of use. The shipment of oxygen has been facilitated by the employment of large "Dewar flasks" for transportation. These flasks are insulated, nonpressure containers with a capacity of 62,000 lb of liquid oxygen. They may be shipped by rail or truck and delivered to insulated storage tanks provided with vaporizing equipment on the user's property.

Utilization. The employment of oxygen in many industrial processes is sure to be facilitated by its low cost. Among the most important will be the manufacture

of synthetic liquid fuels from coals, natural gas, and oil shale and the improvement of metallurgical processes. In the steel industry it is being used in open-hearth and electric furnaces and experimentally in at least one blast furnace at this date. In the open hearth, oxygen has the advantage of a faster heat time, although this time saving cannot be made effective until the flow of material through the mill has been accelerated correspondingly. In the electric furnace, oxygen is reported to improve the quality of alloy steel, shorten the time of the heat, and increase the number of tons per operator hour, as well as permit larger tonnages of stainless scrap being charged with an improved chromium recovery. The erection of more oxygen plants at steel mills seems assured. The metallurgy of other metals may be benefited in a similar manner.

The mining industry has utilized liquid oxygen explosives in a limited manner for years. This explosive consists of liquid oxygen mixed with a carbonaceous absorbent that can be detonated. There is interest at present in the use of oxygen to produce a hot flame by which rock may be pierced.^{1a,1b,9} The rock is fused, and the resulting slag is blown from the hole by the blast of the gases, producing a hole equivalent to that ordinarily obtained by drilling with a steel drill. This process has great significance in the future development of large-scale mining of ores on the Iron Range and elsewhere. Coal-mine gasification, the controlled combustion of unmined coal to produce a fuel gas, progresses more efficiently with enriched air and the gas recovered has less dilution with nitrogen and hence a higher Btu value. A large-scale experiment of this nature now conducted by the U.S. Bureau of Mines is under careful observation.

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PERLITE

Composition and General Description. Perlite is a glassy volcanic rock of about the same chemical composition and appearance as obsidian but differing from obsidian in that it contains 2 to 5 per cent or more dissolved or chemically combined water, while obsidian contains less than 1 per cent. Since it is a rock rather than a mineral it has no fixed theoretical composition. Also, unlike obsidian, when rapidly heated to its softening temperature, usually 1400 to 2500°F, it suddenly expands or "pops," increasing in volume up to 20 times. Perlite and obsidian are apparently the glassy phases of the same magma that produces rhyolite under slower cooling conditions, while pumice and pumicite are the naturally puffed up or exploded phases of the same type of magma. Expanded perlite, then, may be considered as an artificial pumice made from selected materials under controlled conditions.

Pitchstone resembles perlite and obsidian in appearance and composition but contains 5 to 10 per cent water and has a greasy rather than a glassy luster. The accompanying table shows the composition of typical perlites, obsidian, and pitchstone.

ANALYSES OF PERLITE, OBSIDIAN, AND PITCHSTONE

	1	2	3	4	5	6
SiO ₂	73.84	70.19	73.41	70.63	73.79	74.82
Al ₂ O ₃	13.00	12.37	12.34	13.36	12.40	13.61
Fe ₂ O ₃	1.82	1.45	1.33	2.23	0.52	0.25
FeO.....	0.79	0.81	.....	.....	0.62	0.89
MgO.....	0.49	0.91	.....	.....	0.11	0.04
CaO.....	1.52	1.43	0.75	1.69	0.80	0.68
Na ₂ O.....	3.82	3.03	2.95	2.93	3.16	1.98
K ₂ O.....	3.92	3.57	5.33	5.16	4.84	2.99
H ₂ O +	0.53	6.48	3.70	2.84	3.24	3.86
H ₂ O - .....	.....	.....	.....	.....	0.25	0.22
TiO ₂	0.14	0.07	.....	.....	0.09	0.28
P ₂ O ₅	0.01	0.03	.....	.....	0.01	.....
MnO.....	0.07	0.02	.....	.....	0.02	0.04
FeS ₂	0.02	.....	.....	.....	.....	.....
Ignition loss.....	.....	.....	3.70	2.30	.....	.....
Total.....	99.97	100.36	99.81	98.84	99.66	99.66
Expansion temp., °F.....	1751	1949	1700	2200(?)

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Physical Properties. *Hardness*, 5.5 to 7. *Specific gravity* (before expansion), 2.23 to 2.40. *Melting point*, 1400 to 2400°F. *Index of refraction*, 1.483 to 1.506. *Color*, gray to grayish black. *Streak*, white. *Luster*, pearly to dull glassy. *Transparency*, translucent (on thin edges) to opaque. *Tenacity*, brittle. *Fracture*, shelly, more or less concentric, or columnar, splintery, or bladed. At times may include loosely bonded, nearly spherical black glass (obsidian) balls up to 1 in. or more in size, called "marekanites."

Occurrence. Perlite occurs in beds or irregular masses up to 100 ft or more in thickness and up to several square miles in area in geologically recent volcanic series of rocks. With increasing geologic age natural glasses tend to devitrify or crystallize. Thus, perlite deposits would not be expected in areas that contain no recent volcanics. In the United States all the known perlite deposits are in the far western states.

United States. *Arizona.* The largest production of perlite in this country, so far, has come from Arizona.^{8,9} Most important is an area 10 miles long by 2½ miles wide, 3 to 7 miles from Superior, Pinal County. Here commercially important deposits, essentially flat lying, vary in thickness from 40 to over 100 ft, underlying glassy rhyolite and overlying tuff or breccia. Other deposits are known in the southern and middle portions of the Black Mountains of Mohave County.

Oregon. A deposit of perlite 30 to 150 ft thick is being mined on the Deschutes River in southern Wasco County, 14 miles south of Maupin. The rock, after crushing and screening, is shipped to expanding plants at St. Helens, Ore., and Grand Rapids, Mich.

California. Deposits of perlite have been reported in Riverside, San Bernardino, Inyo, Napa, Lassen, and Modoc counties. One of the most promising from a commercial standpoint, due to its proximity to transportation and markets, is 2 miles east of Rutherford in Napa County.

Other States. Deposits of perlite occur near Beatty and at other points in Nevada. Deposits are also reported in Colorado and New Mexico.

Other Countries. Although the expansion properties of perlite and pitchstone were reported in Japan in 1929⁵ and a sort of expanded obsidian was made on a small scale in Germany prior to 1937, no important commercial development has been reported outside the United States.

Production. Although experimental production in this country began about 1941, commercial production started in 1946, when five companies reported a total production of 4,206 short tons. Four shipping mines were in the Superior, Ariz., district and one near Beatty, Nev. In 1947 the Oregon deposit began commercial production with 2,623 tons of raw rock mined and milled. Of this production 2,130 tons were furnaced at St. Helens, Ore., and produced 68,771 bags of expanded perlite of 4 cu ft each. In 1948 production of 13,530 short tons was reported in the United States. Shipments amounted to 9,868 short tons valued at \$184,306.

Mining and Processing. The industry is so new that no standardized methods of mining have been developed. The Deschutes River, Ore., deposit was explored by underground drifts and raises, but it was planned to operate it as an open

quarry. A 30-ton pilot mill was built in 1946 to crush, wash, and size the perlite before shipment to the expanding plant. The rock is crushed wet in a jaw crusher set to 1 in. and ground to 20 mesh in a rod mill in closed circuit with a vibrating screen. Since it is important to later processing that all fines smaller than 200 mesh be removed, the 20-mesh product is washed in a hydroseparator, settled, and dewatered for shipment.

While all crude perlite must be crushed and sized before expanding, the optimum particle size depends upon the expansion characteristics of the rock, method of furnacing, and type of product to be made. The ratio of expansion and the desired size of the finished product will more or less limit the sizing of the raw feed. Since the freight rate on the crude ore is much less than on the expanded product it is usual for crushing and screening to be done at the mine and the expanding to be done at some point within an important market area. As in the case of vermiculite it is to be expected that expanding plants will be located at strategic points throughout the country and sized rock shipped to them. A start on this program has been made already with an expanding plant at Grand Rapids, Mich., and another reported at Philadelphia.

King⁴ has presented an excellent discussion of the factors that control quality in the expanded perlite, as well as of the types of furnaces used. He states:

These variations [in raw material] in chemical composition strongly affect the softening point or viscosity at a given temperature, the type and degree of expansion, the size of the bubbles, the wall thickness between bubbles, and the porosity of the resulting product; as well as other physical properties of the expanded material. . . . In general a perlite rock containing over 74 per cent silica and over 12 per cent alumina with less than 5 per cent combined alkalies (sodium and potassium oxides) and less than 2 per cent total water (ignition loss) will actually require over 2000°F expansion temperature and a relatively long time (on the order of many seconds rather than fractions of a second) in the hot zone and will tend to yield a relatively heavy but strong and minutely vesicular product. Likewise, a perlite in the range of 70 per cent silica, less than 14 per cent alumina, more than 8 per cent combined alkalies, with appreciable iron and/or manganese oxides (3 or 4 per cent combined), and with over 3 per cent total water will usually expand in a temperature range of between 1300 and 1700°F; will tend to yield a relatively lightweight, coarsely vesicular and friable product; and will require a relatively short time contact at maximum temperature, (on the order of fractions of a second to a second or two).

If several different types of product are to be made it is evident that furnace design must allow for accurate temperature control and accurate but adjustable timing of the raw material in the hot zone. Some preconditioning may be done with a high-water perlite by slow preheating to permit the escape of part of the water without expansion, followed by furnacing at proper "popping" temperature. Many types of furnaces and retorts have been built and patented, including horizontal or inclined stationary furnaces, horizontal or inclined rotary furnaces, and vertical mechanical furnaces (described by King). Perhaps no one type of furnace is adaptable to all types of ore. King notes the suggested use of electronic, high-frequency induction heating, which "heats the particles of rock from the inside out and produces perfect three-dimensional expansion and a product of very high strength ratio."⁴

Grades and Prices. Expanded perlite products may be made with bulk densities ranging from as low as 2 lb to as high as 45 lb per cu ft, with grain size ranging from under 325 mesh to a maximum of around $\frac{1}{4}$ in. In general, the lower the bulk density, the lower the compressive strength when used in mortar or as a concrete aggregate. The heat- and sound-insulating values, however, increase with lower bulk density. Thus, the type of product made depends upon intended use, or possible uses depend upon the type of products that can be made. In general, perlite producers aim at a bulk density of 12.5 to 15 lb per cu ft for the usual run of products.

Prices have not yet become stabilized, but late in 1947 processed perlite was selling in California at from 15 to over 50 cents per cubic foot. The average price in Los Angeles for plaster aggregate was about 35 cents per cubic foot. King⁴ foresees a possible future price range for bagged goods of 16 to 35 cents per cubic foot, with lower prices for bulk shipments.

In 1947 the Perlite Standards Association was formed in California to improve and standardize grades and processes.

Utilization. The largest use for expanded perlite so far is as a wall plaster aggregate in partial replacement of sand. Its chief advantages are saving in weight, saving in labor due to ease of application, and much greater heat-insulation value. Other uses include lightweight concrete aggregates, lightweight brick and other ceramic products, lightweight insulating wallboard, acoustic plaster and tile, heat insulation, sound insulation, and porous supports for catalysts or chemicals; it is also used as a filter aid.

In all these applications perlite must compete with other materials such as natural pumice, diatomite, vermiculite, and lightweight aggregates made from clay, shale, and other materials. Compared with pumice expanded perlite has several marked advantages: (1) it is a uniform product with definite, controllable physical properties; (2) it can be shipped to consuming centers in the crude form as a heavy, concentrated product and there expanded to a finished form (like vermiculite). One disadvantage is that, so far, it cannot be made in large grain size to compete with coarse pumice aggregates.

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PHOSPHATE ROCK

Animal bone has been used for years as a source of phosphate, and its value in agriculture has been recognized universally. This supply is inadequate to satisfy the growing demands of the fertilizer industries, and use of the mineral product has become a necessity. Fortunately, mineral phosphates exist in enormous tonnages sufficient for centuries of use. Wavellite and apatite have been employed as sources of phosphorous compounds, as mentioned in the sections devoted to these minerals. Their use is now unimportant except in Russia, where apatite is the chief source of phosphates.

Composition. Phosphate rock, sometimes called phosphorite, consists of more or less impure noncrystalline calcium-fluorophosphate. It is represented by the formula $\text{Ca}_{10}\text{F}_2(\text{PO}_4)_6$. The term "bone phosphate of lime," commonly abbreviated to BPL, is generally used to express the phosphate content of fertilizers. This is the equivalent of $\text{Ca}_3(\text{PO}_4)_2$. In the analysis of phosphate rock, the chemist generally reports the phosphorous content in terms of phosphorus pentoxide (P_2O_5). The average analyses of some common phosphatic material are given in Table 1.⁹ In addition to the content reported, MgO , Al_2O_3 , Fe_2O_3 , TiO_2 , MnO , Cr_2O_3 , Na_2O , K_2O , CO_2 , and V_2O_5 are found in small varying amounts. Silica (SiO_2) is present due to introduction of sand or silicates as impurities. The presence of vanadium in phosphate rock and the shales associated with it in Montana has created an interest in the commercial possibilities of these rocks as ores of vanadium. The iron and alumina content, commonly referred to as I and A, should be low.

General Description and Physical Properties. Phosphate rock is an earthy substance varying from a hard rock to a granular, loosely consolidated mass. Its color may be brown, gray, bluish gray, white, or black. It varies in apparent hardness from 2 to 5. It occurs as a bedded rock, as concretionary masses or nodules, as river pebbles, or as a loosely consolidated sediment.

PHOSPHATE ROCK

TABLE 1. ANALYSES OF PHOSPHATIC MATERIALS

	P ₂ O ₅	CaO	SiO ₂	CO ₂	F
Florida:					
Land pebble.....	32.49	47.61	8.06	3.21	3.95
Hard rock.....	34.30	48.22	7.17	2.30	3.72
Soft rock.....	30.29	34.41	12.74	1.54	2.64
Tennessee:					
Brown.....	32.81	46.07	8.60	1.51	3.64
Blue.....	31.66	45.69	8.62	1.81	3.60
Idaho.....	32.22	45.74	8.67	1.76	3.38
Montana.....	32.16	46.80	12.49	0.97	4.66
Wyoming.....	30.19	46.22	7.19	4.13	3.54
Morocco.....	35.11	53.0	0.86	4.12	4.24
Tunis.....	27.55	45.93	7.76	5.96	3.46
Nauru Island.....	38.92	54.42	0.20	2.04	2.62
Ocean Island.....	40.32	54.08	0.40	1.06	2.97
Bone ash.....	40.36	54.04	0.45	0.70	0.05
Wavellite.....	33.62	.....	.....	.....	3.95
Amblygonite.....	44.45	.....	.....	.....	4.02

Occurrence. Phosphate rock occurs in such a wide variety of forms and under such differing conditions that it is not supposed that all deposits have a common mode of origin. Possibly some of the smaller deposits resulted from a segregation by meteoric waters of phosphatic matter from igneous rocks. The larger deposits, however, are usually directly or indirectly traceable to animal remains. Merrill says:

The origin of the amorphous, nodular, and massive rock phosphates can be traced more directly to organic agencies. All things considered, it seems most probable that the phosphatic matter itself was contained in numerous animal remains, which in the shape of phosphatic limestones, marls, and guanos have accumulated under favorable conditions to form deposits of very considerable thickness. Throughout these beds the phosphatic matter would, in most cases, be disseminated in amounts too sparing to be of economic value, but it has, since their deposition, been concentrated by a leaching out, by percolating waters, of the more soluble carbonate of lime.*

The reason for the preservation of phosphate during geologic time has been explained ingeniously by Mansfield. He postulates that fluorine is an essential constituent of phosphate rock and tends to keep it stable and insoluble. This is confirmed by the necessity of defluorinating phosphate rock to increase its solubility before use in fertilizers. Volcanic activity occurred at approximately the same time in the United States as the deposition of primary phosphates. The unusual amount of fluorine associated with volcanic gases was available in sufficient quantities to combine with the phosphorus and produce an insoluble phosphate exhibiting a high degree of permanence.

* MERRILL, GEORGE P., "The Non-metallic Minerals," 2d ed., p. 270, John Wiley & Sons, Inc., New York, 1910.

Geographically, phosphate rock is widely distributed over the earth and it occurs in places in exceedingly large deposits. Its value as a fertilizer is so great that it forms a very important item of world commerce. Availability and cost of transportation play a very important part, however, for phosphate rock is a low-priced commodity, as is illustrated by the fact that, while the largest deposits of phosphate in the United States are in the western states, production from this district until 1920 was less than 1 per cent of the total, due to the lack of markets in the West and high freight rates to the East. The importance of this area has increased and in 1946 accounted for 7.2 per cent of the total production of the United States. The phosphate deposits of the world, in the order of their present importance, are briefly mentioned below.

United States. The United States is by far the largest producer of phosphate rock in the world, and has the largest known reserves. Rock phosphates of sedimentary origin have been found in at least 18 states. Commercial production has been reported in Alabama, Arkansas, Florida, Georgia, Idaho, Kentucky, Montana, North Carolina, Pennsylvania, South Carolina, Tennessee, Utah, and Wyoming. Production has been irregular in some areas and not continuous.

Florida. Florida is the leading producer, in part due to the large tonnages of easily recoverable material, and also due to its geographical location near the large fertilizer-consuming centers of the south. Land-pebble phosphate is by far the most important type recovered. The deposits occur east of Tampa in an area about 60 miles long and 30 miles wide in Polk and Hillsboro counties. The principal commercial area lies south of the Lakeland Hills, which are composed of Hawthorn limestone. This is a phosphatic limestone of Miocene age. It is believed to be the source rock from which much of the commercial deposits of phosphate have been derived by weathering, leaving phosphatic concentrations as residual products.

The phosphate recovered varies in size from very fine sand to pebbles up to 1.5 in. in diameter. The bulk of the material averages around 0.5 in. in diameter. In composition, the BPL content varies from 66 per cent to over 70 per cent. Hard-rock phosphate is found in small scattered areas in a belt approximately 110 by 30 miles extending from Suwannee and Columbia counties to Pasco County. Production is now centered near Hernando. Boulders of rock up to masses weighing many tons may comprise from 25 to 30 per cent of the workable horizon. The phosphate when separated from the surrounding matrix is of the highest grade and may contain up to 82 per cent BPL. Soft phosphate rock is a mixture of phosphatic clays and sand. It forms a large part of the matrix of hard rock phosphate and is recovered from the waste ponds. It is also associated with the land pebble in the original sediment. River-pebble phosphate has ceased to be commercially significant. The relative importance of the different types of phosphate produced in Florida, as reported by the U.S. Bureau of Mines, is shown in Table 2.

Tennessee. Brown, blue, and white phosphate are found in Tennessee. The brown variety is the only type now industrially important. It is found in Maury, Giles, Hickman, Lewis, and Sumner counties. It occurs as plates of varying thickness or a porous material that disintegrates to phosphatic sand, the two

PHOSPHATE ROCK

TABLE 2. FLORIDA PHOSPHATE ROCK SOLD OR USED BY PRODUCERS, 1944 TO 1948, BY KINDS

Year	Hard rock			Soft rock*		
	Long tons	Value at mines		Long tons	Value at mines	
		Total	Average		Total	Average
1944	22,500	\$138,952	\$6.18	60,087	\$259,523	\$4.32
1945	63,491	426,061	6.71	71,715	293,433	4.09
1946	100,881	762,127	7.55	97,067	387,708	3.99
1947	79,330	618,330	7.79	88,620	326,064	3.68
1948	48,198	368,586	7.65	69,335	293,927	4.24

Year	Land pebble			Total		
	Long tons	Value at mines		Long tons	Value at mines	
		Total	Average		Total	Average
1944	3,670,208	\$13,136,472	\$3.58	3,752,795	\$13,534,947	\$3.61
1945	4,103,022	15,578,980	3.80	4,238,228	16,298,474	3.85
1946	4,807,563	19,867,339	4.13	5,005,511	21,017,174	4.20
1947	6,314,077	31,975,858	5.06	6,482,027	32,920,252	5.08
1948	6,421,725	37,070,381	5.77	6,539,258	37,732,894	5.77

* Includes material from waste-pond operations.

forms being commonly associated. The brown rock is the product of residual weathering and solution of phosphatic limestones. The deposits, therefore, are found in the limestone horizons from which they have been derived. The two types are recognized. The rim or collar deposits are found where the phosphatic limestone crops out along a hillside or in the face of a cliff. The blanket deposits occur where the nearly horizontal limestone has been exposed over a considerable area and the residual phosphate is available at or near the surface. It is reported that the brown rock seldom exceeds 60 per cent BPL, and much of it is lower grade averaging around 48 per cent.

South Carolina. South Carolina deposits occur in a zone about 70 miles long by 30 miles wide along the coast from Beaufort to 20 miles north of Charleston. Two forms of phosphate are recognized: land rock and river rock. The land rock is soft and chalky and occurs in beds of an average thickness of 8 to 13 in. The width expands in places to 30 in. The phosphatic horizon is found at shallow depths not exceeding 20 ft. It is believed to be originally a marl that has become phosphatized by solutions from an unknown source. The river rock consists of fragments introduced from the land rock and the original phosphatized marl. The BPL content averages around 58 per cent. Higher grade material is produced at times.

Kentucky. Kentucky deposits are of the brown-rock type, occurring in very irregular beds 1 to 6 ft thick under a cover of clay and soil 2 to 10 ft thick. Deposits occur near Wallace, Woodford County; and near Lexington, Fayette County; also in Franklin, Scott, Clark and Jessamine counties. Production in recent years has been unimportant.

Arkansas. Phosphate rock has been reported in Stone, Searcy, Izard, Baxter, Marion, Newton, and Independence counties in the northern part of the state. Phosphate is reported to occur in two horizons. The upper, from 3.5 to 6 ft thick, oölitic in texture, is reported to carry from 55 to 56 per cent BPL; the lower, 2 to 4 ft thick, 30 to 40 per cent BPL. Iron and alumina are objectionably high. The deposits have been worked in a small way for local use.

Western States. The tonnage of phosphate rock available in Montana, Idaho, Utah, and Wyoming is known to be large. Commercial production is now restricted to the first three states. The rock was formed in Mississippian and Permian time. Only the Permian deposits are of commercial interest at present, the Mississippian being of much lower grade. The phosphate beds are contained in the phosphatic shale member of the Phosphoria formation. This has been folded and faulted so that the outcrops are exposed in narrow bands along the flanks of the folds and the edges of faulted areas. The beds display dips varying from 0 to 90 deg. Underground mining is necessary. Three mines have been operated near Garrison, Mont. The ore horizons are 3 to 4 ft thick with some shale partings. The deposit is worked by tunnels, generally driven just below the bed. From each level stopes are driven up the dip that are widened to 60-ft rooms at a maximum. The stopes are separated by 12-ft pillars. Upon completion of a block of stopes, the pillars are robbed, permitting extraction of the rock up to 90 per cent. At Conda, Idaho, phosphate rock is found in two beds, each about 7 ft thick. The BPL content varies from 60 to 70 per cent. Vanadium is found in the phosphatic beds in amounts varying from 0.01 to 1.2 per cent vanadium pentoxide. The deposit is worked by tunnel and sublevel stopes.

TABLE 3. WESTERN STATES PHOSPHATE ROCK SOLD OR USED BY PRODUCERS, 1942 TO 1946

Year	Idaho*			Montana			Total		
	Long tons	Value at mines		Long tons	Value at mines		Long tons	Value at mines	
		Total	Average		Total	Average		Total	Average
1942	115,263*	\$518,659*	\$4.50*	150,402	\$572,464	\$3.81	265,665	\$1,091,123	\$4.11
1943	108,916	561,630	5.16	119,764	488,665	4.08	228,680	1,050,295	4.59
1944	112,565	584,400	5.19	186,434	761,745	4.09	298,999	1,346,145	4.50
1945	123,340	673,627	5.46	150,858	916,288	6.07	274,198	1,589,915	5.80
1946	312,658*	1,805,103*	5.77*	179,944	1,207,054	6.71	492,602	3,012,157	6.11

* Includes Utah as follows: 1942, 1,184 long tons (\$7,410); and 1943 to 1945 none. In 1946 Bureau of Mines not at liberty to show Utah separately.

PHOSPHATE ROCK

The crushed and dried rock is shipped to Anaconda for conversion to phosphoric acid and superphosphate. Part of the interest in these deposits lies in the fact that use of sulfuric acid in the manufacture of superphosphate supplies a market for this material, which is produced in large quantities in the smelting of non-ferrous metals carried on in Montana and British Columbia. The production of phosphate rock in the western states, according to the U.S. Bureau of Mines, is presented in Table 3.

Production by states is given in Table 4 and production by grade in Table 5.

TABLE 4. PHOSPHATE ROCK MINED IN THE UNITED STATES, 1939 TO 1948, BY STATES, LONG TONS

Year	Florida	Tennes- see*	Western States	United States	Year	Florida	Tennes- see*	Western States	United States
1939	2,791,360	1,057,570	139,040	3,987,970	1944	3,486,482	1,413,246	300,274	5,200,002
1940	2,782,956	1,120,551	164,570	4,068,077	1945	3,814,935	1,260,849	323,955	5,399,739
1941	3,417,900	1,301,067	203,216	4,922,183	1946	5,280,402	1,316,107	572,330	7,168,839
1942	2,984,503	1,568,162	266,273	4,818,938	1947	6,381,282	1,489,980	1,239,727	9,110,989
1943	3,274,266	1,866,407	227,294	5,369,967	1948	7,184,297	1,499,547	704,316	9,388,160

* Includes small quantity of apatite from Virginia and in 1938 small quantity of phosphate rock from South Carolina. Includes in 1938 to 1943 some matrix of washer grade.

TABLE 5. PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1946, BY GRADES AND STATES

Grades—BPL ¹ content (per cent)	Florida		Tennessee ²		Western States		United States	
	Long tons	Per cent	Long tons	Per cent	Long tons	Per cent	Long tons	Per cent
Below 60.....	100,938	2	637,053	47	2,433	1	740,424	11
60-66.....	18,759	*	286,416	21	.....	...	305,175	4
68 basis, 66 minimum....	213,556	4	32,581	2	203,857	41	449,994	7
70 minimum.....	838,290	17	220,299	16	357	*	1,058,946	15
72 minimum.....	1,150,749	23	184,857	14	283,899	58	1,619,505	24
75 basis, 74 minimum....	1,448,156	29	.....	...	2,056	*	1,450,212	21
77 basis, 76 minimum....	1,077,158	22	501	*	.....	...	1,077,659	16
Above 85 (apatite).....	157,905	3	893	*	.....	...	158,798	2
Undistributed.....								
	5,005,511	100	1,362,600	100	492,602	100	6,860,713	100

* Less than 0.5 per cent.

¹ Bone phosphate of lime.

² Includes a small quantity from Virginia.

Other Countries. Many countries are producers as is shown in Table 6. Northern Africa, where the mining of phosphate is the largest industry next to agriculture; Russia; and the Pacific islands are the most important.

Morocco. Several beds associated with limestone, clay, and marl are known to occur, varying in thickness from 1 to 30 ft. Beds less than 3 ft in thickness are

not considered commercial. The rock is soft and easily mined with pick and shovel. The material is screened and sorted but does not require washing. After drying, by sun in the summer and fuel-fired driers at other times, it is transported to the coast for shipment by sea. Most of the production moves to Europe. The mines at Kourigha produce rock with a BPL content of 75 per cent; and those at Louis Gentil, with a content of 70 per cent, compared to the phosphates of Algeria and Tunisia, which vary between 58 and 68 per cent. The term "TPL," tricalcium phosphate of lime, is used in foreign trade in place of BPL.

Algeria. The largest mine is located at Djebel Kouif near the Tunisian border, about 165 miles by rail from the port of Bona. The mined material is hand picked, dried to 3 per cent moisture, and conveyed to Bona, where storage is provided as well as loading facilities for shipping. At Tocqueville an open quarry is operated. The rock, which is exceptionally hard, is broken, sorted, and moved 117 miles by rail to the port of Bougie. At Djebel Onk an exceptionally large and rich deposit has been found; the beds vary in thickness from 60 to 200 ft and are amenable to quarrying. Completion of a railroad between Djebel Onk and Tebessa will permit shipment to European ports. Three superphosphate factories are located in Algiers with a productive capacity reported to be over 100,000 tons.

Tunisia. A number of mines under different management are active in Tunisia. The hot climate permits solar drying of the rock. Air separation is employed to raise the grade. Material averaging around 66 per cent BPL can be produced readily. Sfax, Sousse, and Tunis are the shipping ports and are provided with storage and loading equipment. Superphosphate is produced at Tunis, and ground rock for application to the soil at Sfax.

Egypt. A number of phosphate occurrences of commercial importance are known to occur in Egypt. The Safaga and Kosseir occurrences near the Red Sea are the most productive. Others on the Nile are of growing importance and have supplied the only superphosphate manufactured in Egypt.

Russia. Apatite is an important source of phosphate (see Apatite). The deposits on the Kola peninsula are of great size. An intrusive rock covers some 460 miles in which nepheline associated with apatite is found in thicknesses of over 600 ft and miles long. The ore varies from 65 to 70 per cent apatite. Over 2 billion tons of this mineral are estimated to be in reserve. The rock is removed by open-cut quarrying during the summer months and by underground operations in the winter. The apatite is brittle and breaks more easily and to finer sizes than the nepheline. It is possible to make a separation by differential crushing. A portion of this concentrate is treated by flotation to produce a product suitable for the manufacture of superphosphate. The crude apatite is reported to run 30.06 per cent phosphorus pentoxide, equivalent to 65.60 per cent BPL; and the concentrate, 40.22 per cent phosphorus pentoxide, equivalent to 87.88 per cent BPL. The concentrates are shipped to Murmansk for export. Previous to the Second World War exports were made to a number of European countries at the rate of approximately $\frac{1}{2}$ million tons per year. Many other deposits of phosphate rock of the phosphorite type are known. The most important are

located in the Omutninsky district of Viatka province, where production up to 100,000 tons of concentrate per year has been reported; at Egorievsk, about 50 miles from Moscow; and at Syzran, Kineshma, and Sterlitamsk. The largest reserves of phosphate rock reported to date in Asia are located in the Kazak Republic. Total reserves in the various areas known are believed to contain over 1½ billion tons of phosphate with a BPL content running between 20 and 42 per cent. Other deposits are known in the Kara-Kalpak Republic and the Tadzhik Republic.

Islands of the Pacific. Phosphate rock of exceptionally high grade has been found in many islands in the Pacific. They are believed to be the product of the reaction of phosphatic solutions derived from bird guano with coral limestones. Ocean Island, Nauru Island, and Christmas Island have been the most important producers. Ocean Island and Nauru are British possessions. They were seized and held by the Japanese, resulting in destruction of equipment and curtailment of operation, so that production data have not been available since 1941. Normally these islands ship over 1 million tons annually to Australia and New Zealand. Christmas Island, 200 miles south of the western end of Java, is also a British possession. It was seized also by the Japanese, but destruction of mining and loading equipment prevented the recovery of much rock. At Ocean and Nauru Islands the phosphate beds lie on a hard dolomite that projects in sharp cones. This prevents complete mechanization of mining, and hand labor with pick and shovel is used extensively in the recovery of the phosphate rock. This is screened, dried, and loaded for shipping, which is a difficult procedure due to poor harbors, fast ocean currents, and a steeply pitching ocean floor. Makatea Island, a French possession, contains valuable deposits of high-grade material. There are a large number of other islands scattered over immense distances in the Pacific which are small producers but which may become more significant commercially with the passage of time.

West Indies. Many islands in the West Indies are known to possess interesting deposits of phosphate. The most highly developed is located on the Dutch island of Curaçao. In genesis it appears to be similar to the deposits of the Pacific, being derived from guano and limestone. The hard rock is blasted, broken down with hammers, crushed at Fuik Bay, and shipped. Most of the production, averaging around 100,000 tons per year, has been shipped to Europe. The rock is of remarkable purity, containing less than 1 per cent iron and alumina. The fluorine content is exceptionally low, below 1 per cent and frequently around 0.60 per cent. It is therefore a superior article for inclusion in cattle feed and has been shipped to the United States in small tonnages for this purpose.

World production, as assembled by the U.S. Bureau of Mines, is presented in Table 6.

Mining and Milling. The methods of mining and milling phosphate rock vary widely with the mode of occurrence, extent of operations, and location of the deposits. Most of the present output comes from open-cut workings, but the large western deposits will be worked largely by underground methods.

For a detailed description of mining and concentration methods the reader should consult Ref. 22, which contains complete data relative to eastern open-cut

TABLE 6. WORLD PRODUCTION OF PHOSPHATE ROCK, 1940 TO 1946, BY COUNTRIES,
METRIC TONS^a
(Compiled by B. B. Mitchell)

Country ^a	1940	1941	1942	1943	1944	1945	1946
Algeria.....	370,890	446,535	334,550	76,798	220,349	401,304	584,827
Australia:							
New South Wales.....	20	31	118	122	.....	.....	0
South Australia.....	254	8,597	14,182	12,976	4,167	725	20
Western Australia.....	39	21	.....	43	2,251	8,619	0
Austria.....	0	0	0	0	0	0	3,240
Belgium.....	280	36,660	103,300	108,900	52,270	17,990	0
Brazil (apatite).....	0	0	0	6,111	5,216	0	0
Canada.....	325	2,256	1,147	1,316	437	271	52
Chile (apatite).....	32,000	29,123	24,909	37,924	50,840	13,203	0
Christmas Island, Straits Set- tlements (exports).....	241,826	0	0	0	0	0	0
Egypt.....	183,464	111,708	328,440	315,566	318,185	349,374	0
Eire.....	0	0	16,444	17,252	20,300	0	0
France.....	24,260	98,660	113,400	131,020	92,966	60,622	88,924
French Oceania (exports).....	164,170	192,235	176,065	188,385	203,300	259,000	0
Germany.....	1,548	1,043	829	0	0	0	0
India.....	119	81	337	1,215	232	532	0
Indochina, French:							
Phosphate rock.....	24,340	40,310	29,050	19,890	6,850	.....	0
Apatite.....	2,070	30,800	98,800	64,600	300	.....	0
Italy.....	274	.....	0	0	0	0	0
Japan ^c	1,400	1,300	1,400	1,200	3,000	2,000	0
Madagascar.....	495	0	0	0	0	0	0
Morocco, French.....	687,310	493,060	715,410	806,171	1,444,902	1,154,120	2,783,636
Nauru and Ocean Islands ^d	1,263,385	0	0	0	0	0	0
Netherlands Indies.....	34,085	0	24,000 ^e	24,000 ^e	24,000 ^e	0	0
Netherlands West Indies:							
Curaçao (exports).....	6,047	111,995	0	0	7,813	8,770	0
New Zealand.....	.....	.....	.....	9,389	20,251	8,084	11,224
Palestine.....	0	2	2,818	5,384 ^f	4,961 ^f	4,867 ^f	0
Rumania.....	95	.....	.....	.....	0	0	0
Seychelles Islands (exports)...	14,613	18,795	22,347	1,849	5,941	7,090	21,397
South-West Africa.....	869	0	59	164	.....	27	1,665
Spain.....	15,781	13,846	15,232	15,722	17,770	20,349	18,608
Sweden (apatite).....	7,479	31,116	79,395	144,265	160,847	0	0
Tanganyika Territory.....	9	33	25	269	28	0	279
Tunisia.....	1,187,823	1,076,118	879,743	334,678	522,265	706,404	1,399,880
Union of South Africa.....	0	425	9	5,801	21,088	0	0
U.S.S.R. (apatite).....	2,600,000 ^e	2,000,000 ^e	0	0	0	0	0
United States (sold or used by producers).....	4,066,943	4,764,921	4,718,780	5,208,508	5,462,938	5,899,921	6,970,827
Total ^g	10,933,000	9,510,000	7,701,000	7,540,000	8,674,000	8,924,000	11,885,000

^a In addition to countries listed, Angaur Island, China, Formosa (Taiwan), New Caledonia, and Republic of the Philippines produce phosphate rock, but data of output are not available.

^b Data not available.

^c Preliminary data for Noto Peninsula, Honshu, for fiscal year ended Mar. 31 of year following that stated.

^d Exports during fiscal year ended June 30 of year stated.

^e Estimate.

^f Exports.

^g Totals represent only those countries for which statistics are shown.

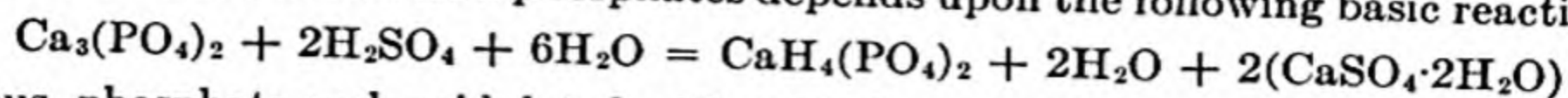
production and western underground mining, together with numerous flow sheets of milling operations. The production of phosphate now involves the most modern applications of chemical engineering and mineral preparation with mechanization of every possible operation. Capital investment, therefore, is high and can be justified only by proved reserves of suitable material. The principles of exploration, production, and concentration are basically similar in the eastern United States, where strip mining is universal. They vary in detail, depending upon local conditions and the judgment of the operating and engineering staff. They are designed to produce a finished product of commercial grade from raw materials exhibiting considerable variation in composition. A prospective deposit is drilled to determine the tonnage available. The drilling samples are analyzed to determine the content of the rock in BPL and the amount of impurities. The size of the phosphate masses is also noted, particularly since the application of flotation has made possible the recovery of fine material, 1 mm and less in diameter. The locations of the washing plant, waste ponds, pumps, and overburden disposal are planned to allow the most efficient operation. Stream pollution by muddy discharge waters must be avoided. Settling ponds to allow only a clear effluent are necessary.

Draglines have come into almost universal use for the removal of overburden and the underlying phosphatic layers. They have displaced the hydraulic methods formerly employed. Following the removal of the overburden the phosphate is commonly thrown into a well from which it is pumped to the washing plant. For many years the washing operation was a simple procedure consisting of liberation of phosphate pebbles from the surrounding sand and clay with water. The disintegrated product was screened, producing a coarse and fine phosphate concentrate, marketable after drying. The loss of fine phosphate was high. The introduction of the flotation process in 1927 has had a profound effect on the industry. It has permitted the recovery of large tonnages of fines previously wasted. It has increased reserves, since it allows the successful treatment of areas previously considered to be too high in fines to be of commercial interest. Table agglomeration was added in 1929. Either flotation or agglomeration or the use of both is now common practice in the treatment of fines. Spirals may be used in place of tables.

Briefly, the common treatment of the mined rock is to disintegrate it with water. The slurry is screened with the removal of some coarse sizes for further reduction in size. The coarse material is then fed to log washers, generally in a series of two or three with intermittent screening. The concentrate from the log washers is sized to $\pm \frac{1}{2}$ in., dried, and stored for shipment. The overflow from the washers is screened to recover any coarse material carried over and then conveyed either to waste ponds for settling and recovery of water for reuse or, if recoverable fines are present, to a recovery plant equipped with flotation cells or tables. The whole operation is under exact scientific control, and losses are reduced to a minimum with the production of a high-grade final concentrate.

Utilization. By far the largest use for phosphate rock is in the manufacture of acid phosphate, superphosphate, or other soluble phosphatic salts for fertilizers, although an increasing quantity is being used in the raw state as a fertilizer.

The manufacture of acid phosphates depends upon the following basic reaction:



Thus, phosphate rock acidulated with sulfuric acid gives calcium acid phosphate plus gypsum. The proportion of acid used depends upon the amount and nature of impurities present, fineness of ground rock, etc. The general methods used are as follows:

The raw rock is ground, by various methods, so that 80 to 95 per cent or more will pass through a 100-mesh sieve, and is then mixed in batches of 1 to 2 tons in a mixing pan, with about an equal weight of sulfuric acid of about 50°Bé. One type of mixing pan is a revolving, round cast-iron pan fitted with one or two sets of stirring arms or ploughs revolving at a higher speed. When thoroughly mixed, the mixture is dumped through bottom doors into a square brick or concrete chamber below, called a "den." When the reaction is completed or the mass has cooled to about 150°F (12 to 48 hr), the mass is excavated by hand into elevating and conveying systems, which carry it to storage piles. The finished product, when properly made, is a dry powdery substance containing 14 to 18 per cent phosphorus pentoxide. In the shipping season the acid phosphate is reclaimed from the dumps; pulverized; mixed with ammoniates, potash salts, fillers, etc., to make complete fertilizers; and bagged for shipment by bagging machines.

As the phosphoric anhydride (content of acid phosphate) is, at the maximum, only about 18 per cent, it is, in reality, a rather low-grade product and will not stand high freight charges or long shipments.

TABLE 7. PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY USES AND STATES

Uses	Florida		Tennessee ^a		Western States		United States	
	Long tons	Per cent of total	Long tons	Per cent of total	Long tons	Per cent of total	Long tons	Per cent of total
Domestic:								
Superphosphates.....	3,959,108	79	449,496	33	195,838	40	4,604,442	67
Phosphates, phosphoric acid, phosphorus, ferrophosphorus.....	231,338	5	653,885	48	9,278	2	894,501	13
Direct application to soil....	314,575	6	212,405	16	1,117	^b	528,097	8
Fertilizer filler.....	32,303	1	18,454	1	.....	.....	50,757	1
Stock and poultry feed.....	52,501	1	500	^c	.....	.....	53,001	1
Undistributed ^d	1,047	^b	27,860	^c	2,081	^b	30,988	^b
Exports ^e	414,639	8	.....	.....	284,288	58	698,927	10
	5,005,511	100	1,362,600	100	492,602	100	6,860,713	100

^a Includes a small quantity from Virginia.

^b Less than 0.5 per cent.

^c Revised.

^d Includes phosphate rock used in pig-iron blast furnaces, parting compounds, research, defluorinated phosphate fertilizers, refractories, and other uses.

^e As reported to the Bureau of Mines by domestic producers.

Triple superphosphate has been produced by the use of phosphoric acid in place of sulfuric acid. The term "double superphosphate" is in more common use. Either term applies to a product manufactured by a similar process employing phosphoric acid and containing from 45 to 50 per cent available phosphorus pentoxide. The use of the electric furnace has become well established in the manufacture of elemental phosphorus. This product is converted into chemical compounds and during the war was produced in large quantity for use in smoke screens. The industrial importance of phosphorus compounds is increasing steadily; among others the sodium phosphates have shown a large gain as detergents and water-softening compounds. The chemical field may be expected to display a steadily increasing importance as a consumer in the future. Consumption by tonnages as reported by the U.S. Bureau of Mines is shown in Table 7.

Marketing and Prices. Phosphate rock is sold by the long ton. In 1950, pebble at various grades was quoted fob Florida as follows:

<i>Per Cent</i>	
77-76	\$6.90
75-74	5.80
72-70	4.80
70-68	4.15
68-66	3.75

A considerable portion of the phosphate rock produced is consumed by the miner and does not find its way to the open market.

Competition. Phosphate rock has little competition in the United States except in a small way from animal bone. In prewar years, phosphatic slags produced in the smelting of phosphatic iron ores was a valuable source of phosphorus compounds in European countries. The steel industry supplied much of the phosphate used in the maintenance of soil fertility. Total output at times exceeded 5 million tons annually. Germany was the largest producer, contributing 2,500,000 tons annually. France had an output of approximately 1 million tons annually. This source is now greatly curtailed due to destruction of steel-manufacturing capacity. In the United States the type of iron ore so far available has been of such high grade and so free from impurities that the evolution of phosphatic slags has never reached significant proportions or furnished any competition to the natural rock.

Phosphate Rock as a Source of Fluorine. The growing usefulness of fluorine compounds has been mentioned in the discussion of their principal source, fluor-spar. The necessity of the elimination of most of the fluorine to increase solubility of the phosphate has been mentioned. Some of this fluorine has been recovered as a by-product, mostly as sodium-fluosilicate. The large reserves of phosphate available and the large tonnage treated annually, much of it carrying 3.8 per cent fluorine, suggests that phosphate rock may become an important source of this element.

Reserves. The world's largest reserves lie in the United States, Russia, and North Africa. Mansfield¹⁷ has made a detailed study of the difficult problem of

the determination of tonnages available for future use. His report is given in Table 8.

TABLE 8. PHOSPHATE RESERVES OF THE UNITED STATES
Thousand Long Tons

East:	
Florida.....	5,081,839
Tennessee.....	194,468
South Carolina.....	8,798
Kentucky.....	863
Arkansas.....	20,000
West:	
Idaho.....	5,736,335
Montana.....	391,323
Utah.....	1,741,480
Wyoming.....	115,754
Total.....	13,290,860

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PINITE

Composition and General Description. Pinite is a massive, compact rock composed almost entirely of extremely fine grains of sericite, a secondary potash mica, associated with small amounts of andalusite and pyrophyllite. It is considered to be the product of hydrothermal alteration of rhyolites or of volcanic ash or tuff; also of cordierite, spodumene, nepheline, scapolite, feldspar, and other minerals. It resembles massive talc or pyrophyllite but is somewhat harder. Analysis, as reported by Kerr,² shows it to be essentially a hydrous potassium aluminum silicate. An average analysis of four samples from the only commercial producer, located in Nevada, as reported by Page, Raine, and Sullivan,³ is as follows:

AVERAGE ANALYSIS OF NEVADA PINITE

	<i>Per Cent</i>
SiO ₂	50.47
Al ₂ O ₃	37.41
K ₂ O, Na ₂ O.....	5.44
Ignition loss.....	5.62
	99.34

Potassium is the dominant alkali and is present in greater quantity than soda.

Physical Properties. Amorphous; cryptocrystalline to finely granular. *Hardness*, 2.5 to 3.5. *Specific gravity*, 2.6 to 2.85. *Melting point*, inverts to mullite; pyrometric cone equivalent (PCE) 32. *Color*, grayish white, grayish green, pea green, dull green, brownish, or reddish. *Streak*, white. *Luster*, dull to waxy. *Fracture*, irregular to subconchoidal. *Transparency*, translucent to opaque.

Occurrence. The only commercial producer is located on the east side of the Humboldt Range near Rochester, Nev. It is about 25 miles from Oreana, Nev., the nearest railroad point. The main body of material, exposed over a width of 40 ft for a length of 450 ft, is white to gray in color and easily scratched with a knife. It is remarkably free from quartz. Silicified tuff is present above and below the pinite. The deposit was discovered in 1933, and exploration by trench and quarrying has proved the existence of a large tonnage of uniform rock. Car-load shipments have been made to Pittsburgh, Calif., where it has been processed

by calcining. Production data are not available since tonnage figures have been included with those for crude talc.

Utilization. Pinite has one property of outstanding value: upon heating it inverts to mullite, a material of steadily growing importance as a refractory. Page, Raine, and Sullivan³ list the valuable properties of pinite as follows: it is easily ground; it inverts to mullite at a relatively low temperature; it has a low firing shrinkage and a high density after firing; it makes a snow-white product exhibiting extreme hardness and superior resistance to abrasion. Refractoriness is high (PCE 32). It has a relatively low and uniform thermal expansion; free silica is absent; and it is resistant to molten enamel slags.

Pinite is used chiefly in making mullite-rich refractories. These have been found to be highly useful in the rotary kilns used in making portland cement and lime. Other high-temperature refractory uses are indicated. If other extensive commercial deposits were found it is probable that pinite would become much more widely used.

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POTASH SALTS

Potash is of such great economic importance and the sources of potash and methods of production are so numerous and so diversified that the literature of the subject is extensive. The field is so wide that it cannot here be covered adequately, even briefly. No attempt will be made to describe all the sources of potash or all the methods of production. A brief survey of the subject will be made and for further information reference should be made to the works noted in the bibliography at the end of this section.

Definition of Potash. Potash, properly speaking, is potassium oxide (K_2O), but potassium carbonate (K_2CO_3) is also sometimes (although incorrectly) called "potash." The "potash" salts of commerce do not necessarily contain potassium oxide—for example, potassium chloride (KCl)—and they should more properly be called potassium salts. The term "potash salts," however, is now generally accepted, and all the compounds of potassium are known commercially as potash salts.

Potash salts are usually sold on the basis of their "potash" content. In other

words, the potassium content is recalculated to its equivalent of K_2O and expressed as "potash." Thus, potassium chloride (KCl)—often called "muriate" commercially—with a theoretical content of 52 per cent potassium and 48 per cent chlorine, has a theoretical "content" of 63 per cent "potash" (K_2O). This mode of expression is used to afford a common basis for the commercial comparison of all potassium salts.

The potassium and potash content of common salts and minerals is listed in Table 1.

TABLE 1. POTASSIUM AND "POTASH" IN POTASSIUM COMPOUNDS

Name	Symbol	Percentage of potassium (K)	Chemical equivalent in terms of "potash" (K_2O)
Element:			
Potassium.....	K	100	120
Potassium salts or "potash salts":			
Potassium chloride (mineral sylvite).....	KCl	52	63
Potassium muriate (same as chloride)			
Potassium sulfate.....	K_2SO_4	45	54
Potassium nitrate (saltpeter).	KNO_3	39	47
Potassium carbonate.....	K_2CO_3	57	68
Potassium hydrate or caustic potash.....	KOH	70	84
Potassium cyanide.....	KCN	60	72
Stassfurt minerals:			
Carnallite.....	$KMgCl_3 \cdot 6H_2O$	14	17
Kainite.....	$MgSO_4 \cdot KCl \cdot 3H_2O$	16	19
Sylvite (potassium chloride)..	KCl	52	63
Langbeinite.....	$K_2SO_4 \cdot 2MgSO_4$	9	23
Polyhalite.....	$2CaSO_4 \cdot MgSO_4 \cdot K_2SO_4 \cdot 2H_2O$	7	16

Sources of Potash. For some years prior to the First World War the only sources of potash that were of great commercial importance were the deposit of soluble potash salts of the Stassfurt district of Germany and similar deposits in Alsace. During the war these sources were shut off and a world-wide search was made to develop new sources for the potash so vitally needed both for agriculture and for munitions. Many sources were developed and considerable production resulted. Costs were very high, however, and after the war when the European sources again became available most of the new enterprises were forced to suspend operations. The principal sources of potash, of importance both under normal conditions and in emergencies, may be summarized briefly as follows:

POTASH SALTS

- I. Inorganic sources:
 1. Deposits of soluble salts, *e.g.*, Stassfurt deposits
 2. Saline solutions:
 - a. Salt lakes and pans, *e.g.*, Searles Lake
 - b. Sea water, *e.g.*, at Girand, France
 3. Insoluble potash minerals:
 - a. Alunite, *e.g.*, Marysvale, Utah
 - b. Greensand, *e.g.*, New Jersey greensand
 - c. Leucite, potash slates and shales, feldspars, and other silicates
 4. By-products in other processes:
 - a. Portland-cement kiln dust
 - b. Blast-furnace flue dust
- II. Organic sources:
 1. Vegetable sources:
 - a. Kelp or seaweed
 - b. Wood ashes
 - c. Sunflower stalks, tobacco stems, sagebrush, water hyacinth, prickly pear, and other vegetable material
 - d. Molasses distillery waste and waste liquors from beet-sugar molasses
 2. Animal sources:
 - a. Wool washings
 - b. Ash from animal excrement
 - c. Potassium nitrate of organic origin

Deposits of Soluble Salts. Deposits of soluble potash salts have been for many years the chief commercial sources of potash and are likely to maintain this position for many years to come. The largest and most important deposits of this class are those of the Stassfurt district in Germany. Similar but probably somewhat smaller deposits occur near Wittelsheim in Alsace, and in Spain, Canada, Poland, Russia, and possibly England. The discovery of similar deposits in the United States made the country independent of imports from foreign sources.

Potash deposits of minor present importance have been reported in Holland, Denmark, Russia, Peru, Ethiopia, and a few other countries.

Germany. The *Stassfurt potash deposits*, discovered about 1857, cover an area of about 100 square miles in the vicinity of Stassfurt, extending to Thuringia on the south, Hanover on the west, and Mecklenburg on the north. It has been estimated that these deposits occupy a volume of 10,790 million cu m, containing 20,000 million metric tons of potash salts, a quantity sufficient to supply the world's needs for 2,000 years at the present rate of consumption.

In these deposits occur over 30 saline minerals, chiefly chlorides, sulfates, and borates of potassium, sodium, calcium, and magnesium. In addition, varying but usually minor amounts of carbonates, sulfur, pyrite, bromine, iodine, ammonium, and nitrates are sometimes present.

Several borates are also found, but they are relatively rare except boracite.

The most important minerals commercially are carnallite and kainite.

The salts are removed from the ground by underground mining methods. Some of the crude salts may be simply crushed and sold directly for fertilizing

purposes, but most of the ore is treated by a process of solution and recrystallization, making various products of varying degrees of purity for different uses. For fertilizer purposes the following grades are commonly made:

<i>Type</i>	<i>Grade</i>
Kainite.....	14-16% K_2O
Kainite.....	12.4% K_2O
Manure salts.....	20% K_2O
Manure salts.....	30% K_2O
Manure salts, double.....	48% K_2O
Muriate (KCl).....	80-85% KCl (50-53% K_2O)
Sulfate (K_2SO_4).....	90-95% K_2SO_4 (48-51% K_2O)

In addition, a great range of pure potassium, sodium, magnesium, and calcium chemicals is made. Epsomite, glauber salt, magnesium chloride, calcium chloride, and bromine are important by-products.

Next to coal, potash is the most important mineral raw material produced in Germany. These deposits were important to the United States prior to the development of domestic sources. In 1948 Russia controlled 61 per cent of the German production.

France. Alsace Deposits. Deposits of potash salts were discovered by drilling in 1904 at Wittelsheim, 6 miles northwest of Mulhouse in southern Alsace. Later developments indicated that the deposits underlie an area of about 65 square miles, chiefly in the plain bounded by the Jura, the Vosges, and the Rhine. Drilling has disclosed the presence of potash salts in southeast France near Bayonne.

The deposits consist of two beds, a lower bed averaging 10 to 16 ft in thickness, and an upper bed, about 60 ft higher and 3 to 5 ft thick. The lower bed occupies a much larger area than the upper bed. The beds occur at an average depth of about 2,000 ft and are remarkably uniform.

The salts consist essentially of silvinite, a mixture of sylvite (KCl) and rock salt. Practically no carnallite or magnesium chloride is present. Thus, the crude salts may be used directly for fertilizing purposes, and the preparation of pure potassium chloride is very simple and cheap. The crude salts are of considerably higher grade than those of the Stassfurt district, averaging, in place, about 22 per cent potassium oxide. It has been estimated that the known deposits contain 1,472,058,000 metric tons, averaging 22 per cent potassium oxide, or the equivalent of over 300 million tons of pure potassium oxide.

Spain. Potash deposits were discovered in Spain in 1913. Production was started in 1925 and has increased rapidly in importance, since the deposits are situated 40 or 45 miles northwest of Barcelona in an area between the towns of Vich and Balaguer about 75 miles long and having a maximum width of 15 to 18 miles. The principal discoveries have been made near the villages of Cardona, Suria, and Sallent. Exploration has proved the presence of high-grade material containing up to 18 per cent potassium oxide at Sallent. Exploitation has been facilitated by the shallowness of the productive horizons, 300 to 600 ft from the surface, and the proximity of the port of Barcelona.

India. The deposits of potassium nitrate in eastern Punjab have been noted in the section dealing with nitrates.

Russia. Large deposits have been reported within the U.S.S.R. Data relative to the extent of exploitation and reserves for future use are not available.

The principal point of production is located at Solikamsk on the western slope of the northern Urals. The deposits occur in a Permian basin that was once part of the sea extending from the Arctic to the Caspian. Productive capacity was increased rapidly in the 1930's, and the mines were mechanized with modern equipment. A goal of 3,000,000 tons of mine-run salts was established for 1937. A production of 1,800,000 tons was reported. The principal economic mineral is reported to be sylvinite, a mixture of sodium chloride and potassium chloride, which is present to the extent of 22 per cent, equivalent to 14 per cent potassium oxide. Reserves of potassium salts have been estimated at 15 billion tons. Further discoveries have been made at Ozinki, Sagis, and Akjar in the southern Urals. A rapid development of these deposits was urged to supplement production from Solikamsk and to avoid the long haul from that point to central Asia and the Ukraine. Russia possesses the necessary raw materials to become an influential factor in the world potash situation due to her own resources, the acquisition of the former Polish fields, and a partial control of German production.

Poland. The potash deposits are located in Galicia, formerly a part of Austria, which was incorporated in the Polish state as a consequence of boundary adjustments made after the First World War. The principal potash mineral mined is sylvite, which has been recovered in quantities approximating $\frac{1}{2}$ million tons per year. The next most important mineral is kainite, followed by langbeinite. The area, including the district south of Lwow, with the potash mines at Kalusz, Stebnik, and Holyn, was ceded to the U.S.S.R. following the German conquest.

England. The potassium salts sylvite and polyhalite were discovered during oil-well drilling during the war years. They were found in North Yorkshire in a horizon located at a depth of 4,000 ft. No commercial exploitation has been attempted. It is believed that the cost of mining would be too high to allow economic operation.

Canada. Extensive fields of potash salts were found in 1946 in the province of Saskatchewan. They were encountered while drilling for oil and gas at a depth of 3,466 ft in an area about 100 miles northwest of Saskatoon. The potash beds are reported to range in thickness from 9 to 28 ft with a potassium chloride content of up to 65.6 per cent and a potassium oxide content averaging 21.5 per cent. The beds are believed to extend to the south for hundreds of miles, possibly into North Dakota and beyond. Exploration as to the extent of the deposits is being continued by drilling.

Palestine. The concentrated brines of the Dead Sea contain enormous quantities of potassium salts in solution. It is estimated that the annual input from the Jordan River is equivalent to 40,000 tons of potassium chloride. The potassium chloride content of the sea water sampled at a depth of 5 m is reported to be 11.8 g per l. The potassium chloride content of the Sea is estimated at 2 billion tons. Because of rugged terrain, choice of plant location was restricted.

Two plants have been constructed, one at Kallia and one at Sodom. Sea water is pumped from a depth of 175 ft, where it has been found that the potash and bromine percentage is about 50 per cent higher than at the surface. The sea water is treated by solar evaporation in ponds constructed on the ground. Evaporation is rapid due to the hot and arid climate. Most of the salt, sodium chloride, is deposited in the first pond. The remaining brine is then moved to a second pond where carnallite, $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, together with some adhering sodium chloride is precipitated. The carnallite is removed and washed in a series of brines of varying magnesium content. The last wash using a brine low in magnesium chloride removes the magnesium chloride from the carnallite, and potassium chloride is left. This receives a number of washes from brines and finally water and then is filtered and dried. The average commercial product averages 97 per cent potassium chloride. Material of higher purity can be prepared by recrystallization. Suspension of operations due to unsettled political conditions accompanied by at least partial destruction of one plant was reported in 1950.

United States. The development of the potash industry in the United States has been described in detail by Smith.²¹ The production of potassium carbonate from wood ashes was the first chemical industry in the country and was active in the 1600's. Smith reports that from the War of the Revolution until after the Civil War, exports varied in annual valuation from \$500,000 to \$2,000,000 and the price per ton from \$100 to \$200. The material was shipped to England and France and formed the first chemical export of the country. The hardwoods of the northern states were the most productive, and maple and elm were the most desired. The abundance of forest land and the necessity of clearing it for agricultural purposes led to an active industry. An ashery was as common as the general store in most areas in New England and New York. It served as a collection point for the ashes produced in the district and as a crude chemical plant in which the potash, mostly in the form of impure potassium carbonate, was recovered by leaching with water that was boiled to cause precipitation of the crude salts.

The development of an industry using the imported Stassfurt salts was begun in 1864, and mineral potash soon displaced that from organic sources. The German and later the French production was marketed aggressively in the United States and soon controlled the industry. The United States became totally dependent on imported material, a position from which it was rudely shaken by the embargo placed by Germany on export shipments in 1915. The subsequent search for potash, which was in great demand due to the soaring industrialization of the First World War, led to the temporary utilization of all known sources. Nearly all the materials listed under Sources of Potash were used. The most productive were the salt lakes and pans. In 1918 total domestic production amounted to 54,803 tons of potassium oxide—a record to that time. More significantly it resulted in a systematic survey and exploration of the mineral potash resources of the country, which terminated in discoveries of such magnitude as to make the United States permanently independent of foreign imports.

POTASH SALTS

Searles Lake. Searles Lake is located in the northwestern part of San Bernardino County, Calif. It is located at an elevation of over 1,600 ft above sea level but in an area of such light precipitation and high temperatures that permanent accumulation of water is impossible. The surface is covered with water at intervals. Most of the time it is a typical playa, covered with crystals of soluble salts precipitated from the evaporating brines. This crust of salts is of sufficient strength to support traffic. The void space between the individual crystals approximates 25 per cent. This is filled with a saturated brine of remarkable composition. The level of this brine is generally 6 in. below the surface of the playa. The brine has a specific gravity of 1.30 and a pH of 9.48. Analysis is shown in Table 2, according to Gale.²⁶

TABLE 2. TYPICAL ANALYSIS OF SEARLES LAKE BRINE

KCl.....	4.70
NaCl.....	16.35
Na ₂ CO ₃	4.70
Na ₂ SO ₄	6.96
Na ₂ B ₄ O ₇	1.50
Na ₃ PO ₄	0.16
NaF.....	0.01
Other minor constituents.....	0.30
	<hr/> 34.68
Water.....	65.32
	<hr/> 100.00

Among the minor constituents are included bromine, lithium, iron, arsenic, antimony, tungsten, and iodine. The lake now covers 12 square miles. It is the remnant of a much larger lake that existed in earlier geologic time. The total reserves of soluble salts are large.

Commercial interest in this deposit was first aroused in the 1870's, and the first product to find a market was borax. The industry progressed in a small way and was finally abandoned in 1895 when borax production was concentrated in the colemanite deposits of Death Valley. Interest in Searles Lake was resumed in 1905 when it was realized that salts other than borax could be recovered, and it was investigated as a source of sodium carbonate. Potassium salts were known to occur at an early date, and by 1910 interest in the development of domestic supplies was stimulated by the termination of contracts made between European producers and manufacturers of fertilizers in the United States. This interest grew rapidly, and by 1915 the war embargo placed on shipments from Europe made the procurement of domestic supplies a matter of prime importance to the national economy. Searles Lake became the leading domestic producer of potash until the deposits of New Mexico were in production. It still supplies a substantial percentage of the country's total.

The major problem in the recovery of potassium chloride is its separation from sodium chloride, its most common associate. This is possible mechanically and chemically due to remarkable differences in the behavior of the two compounds. They cannot form isomorphous crystals due to differences in crystal structure

and size of the individual atoms. The most intimate and fine-grained mixtures of potassium and sodium chloride, therefore, are mechanical mixtures and can be separated by mechanical means. The solubility of the two salts varies with increase in temperature, potassium being much more soluble at elevated temperatures than sodium chloride. It is possible to keep potassium in solution while sodium chloride crystallizes and can be removed. This property is utilized by the American Potash and Chemical Corp. at their operation at Trona, Searles Lake. Brine is pumped from wells drilled to 70 ft below the surface of the salt body. The brine is piped about 4 miles to the plant. Here end liquors from previous crystallizations are added and the mixture is conveyed to triple-effect evaporators. As concentration increases, the chloride, carbonate, and sulfate of sodium precipitate and are removed, while potash and borax remains in solution. This solution is cooled and potassium chloride removed by crystallization. Upon further cooling borax and other salts are precipitated. Further treatment by crystallization and other means permits the production of products of specified purity. The entire operation is under precise, technical control. Potassium chloride, borax, soda ash, sodium sulfate, bromine, and lithium phosphate are recovered. A concentrate high in tungsten has been recovered in pilot-plant operation.

Carlsbad, N.Mex. The Permian salt basin of New Mexico, Texas, and adjacent states has been known to contain soluble salts since they were explored first. Salt and gypsum are conspicuous at or near the surface. Potash salts were discovered only after years of geological exploration and test drilling. Cancellation of contracts by foreign producers for delivery of potash salts to the United States in 1910 led to an energetic search for domestic supplies. This was increased by the shortages from 1914 to 1918 incident to the blockade of German shipping. Polyhalite was the first potassium-bearing mineral to be identified in 1921. It was found at a depth of 2,400 ft in a well near Midland, Tex. Subsequent exploration proved the presence of large tonnages of this mineral in the Permian basin. It is not the most desirable source of potash due to its low potassium oxide content, 15.6 per cent, and its comparative insolubility, which complicates treatment. Sylvite, 63.2 per cent potassium oxide, was first found in 1925 in an area east of Carlsbad. Further drilling proved the presence of commercial tonnages of this mineral in large amounts. Sylvite is mechanically mixed with salt, producing a mixture known as "sylvinite." The mining and processing of this material has made the United States independent of foreign sources. Three companies are now engaged in production, the International Minerals and Chemical Corp., the Potash Company of America, and the United States Potash Co.

The mines are worked by vertical shaft to the sylvinite horizon by room-and-pillar method in a ratio of 60:40, using mechanized mining. The separation of potassium chloride from sodium chloride is accomplished by utilization of the differences in solubility at varying temperatures, similar in principle to the process employed at Searles Lake. The adaptation of the flotation process to the separation of the two chlorides has been successful and is now widely used. Potash may be floated and salt depressed, or vice versa, as preferred.

Langbeinite, $K_2SO_4 \cdot 2MgSO_4$, is also produced in commercial quantities. The

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mineral is prepared for market by crushing, washing with water, which removes the sodium chloride generally present, and drying. It is sold as potassium-magnesium sulfate with a 22 per cent potassium oxide content. It is also converted to potassium sulfate and magnesium chloride by a base-exchange process. This involves treatment with a solution of potassium chloride, causing an exchange in bases producing the desired products.

Michigan. Some potassium chloride is obtained by treatment of the brines from salt wells located near Midland, Mich.

Utah. Potassium chloride is produced from the Salduro Marsh brines at a plant near Wendover, Tooele County. This marsh covers over 100 square miles and has a solid surface of crystalline salts. The underlying brine contains approximately 27 per cent solids composed of the chlorides of potassium, sodium, and magnesium. Sodium sulfate is also present. Potash salts were encountered in drilling in Grand County in eastern Utah in the 1920's. The potassium horizon is fairly deep, 2,800 ft and beyond. Analyses of cuttings have shown potassium oxide in excess of 10 per cent. Potassium chloride is common in the brines encountered. Potassium salts have been recovered from alunite as described in the discussion of that mineral.

Production and consumption in the United States are shown in Tables 3 and 4 (figures from the U.S. Bureau of Mines).

TABLE 3. SALES OF POTASH IN THE UNITED STATES FOR CONSUMPTION AND EXPORT, 1944 TO 1946, SHORT TONS OF K_2O

	1944	1945	1946
Deliveries of primary potash of domestic origin by major companies, as from reports of American Potash Institute:			
In United States and possessions:			
Agricultural.....	675,787	724,900	790,928
Chemical.....	82,198	85,169	75,797
For export.....	57,850	58,117	56,402
	815,835	868,186	923,127
Imports for consumption plus sales of minor domestic producers.....	5,364	6,435	5,048
	821,199	874,621	928,175
Total exports (estimate by Bureau of Mines).....	68,880	67,583	65,643
Actual sales for consumption in the United States..	752,319	807,038	862,532

Insoluble Potash Minerals. *Alunite*,* a hydrous sulfate of potassium and aluminum ($K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$), contains, when pure, 11.4 per cent potash (K_2O), 37 per cent alumina (Al_2O_3), and 38.6 per cent sulfur trioxide (SO_3). It occurs in large deposits near Marysvale, Utah, La Tolfa, Italy, and elsewhere. While alunite is insoluble in water and acids, after calcination at a moderate heat (about 500°C) it is partially soluble in both water and acids and has been used as

* See Alunite.

a source both of alum* and of potash. Several processes have been devised for the extraction of potash from alunite, and during the war several plants were in operation near Marysvale, Utah.

In the Chappell process the mineral is crushed to about $\frac{1}{4}$ in. and roasted at about 750°C in rotary kilns to drive off the sulfur dioxide and trioxide. The residue, containing potassium sulfate and alumina, is digested in hot water and filtered. The liquid, containing the potassium sulfate, is evaporated in triple-effect vacuum pans, and a 95 per cent potassium sulfate product is recovered by crystallization. More or less pure alumina (Al_2O_3) is obtained as a by-product. One of the difficulties in the process is the fact that the freeing of the alumina residue of all of the potassium sulfate is difficult and requires great quantities of wash water. This makes the evaporation difficult and expensive.

TABLE 4. POTASSIUM SALTS PRODUCED IN THE UNITED STATES, 1946 TO 1948, BY GRADES, SHORT TONS

Grade	1946	1947	1948
Muriate of potash:			
60-62% K_2O minimum*	1,251,088	1,394,202	1,523,937
48-50% K_2O minimum	122,257	125,120	145,675
Manure salts	98,333	174,145	260,339
Sulfate of potash and sulfate of potash-magnesia	216,057	212,309	208,542
	1,687,735	1,905,776	2,138,493

* Includes refined potash and some 93-96% KCl .

Under normal conditions it has been stated that potash can be profitably produced from alunite only by marketing the by-product alumina in order to pay part of the cost of production.

The *greensand* marl deposits of New Jersey have been a small source of potash in the past, but may be of very great future importance if the extraction of potash from this material can be done cheaply enough to compete with potash from the great deposits of Stassfurt and Alsace. The potash in the greensand marl occurs chiefly in the mineral *glauconite*, which is essentially a hydrous silicate of ferric iron and potassium.

According to Mansfield,[†] the greensand marl belt, in its easily accessible portions, averages about 2.1 miles in width and 40 ft in thickness and extends across New Jersey from near Sandy Hook to the Delaware River near Salem, a distance of about 100 miles. With an average content of 6.6 per cent potash, these beds are conservatively estimated to contain 256,953,000 short tons of potash that could be mined by open-pit methods. If underground mining methods were to be used, the available quantity of potash would be enormously increased.

*Leucite*¹⁸ from the wyomingite deposits of the Leucite Hills of Sweetwater County, Wyo., has recently again become of possible commercial interest as a

* See Alunite.

[†] MANSFIELD, G. R., Potash in the Greensands of New Jersey, *U.S. Geol. Survey, Bull.* 727, 1922, p. 106.

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source of potash due to the development of the very large trona deposits at Westvaco, Wyo., and the development of a base-exchange process for reacting trona with leucite to yield pure potassium and sodium carbonates.*

Greensand was produced and sold in New Jersey in 1946 to the extent of 5,140 tons valued at \$424,900. The entire production was consumed in the manufacture of water-softening compounds.

TABLE 5. WORLD PRODUCTION OF POTASSIUM SALTS AND EQUIVALENT K_2O , 1944 TO 1946, BY COUNTRIES, METRIC TONS^a
(Compiled by B. B. Mitchell)

Country ^a	1944		1945		1946	
	Potassium salts	Equivalent K_2O	Potassium salts	Equivalent K_2O	Potassium salts	Equivalent K_2O
North America: United States, potassium salts.	1,431,982	757,103	1,440,879	793,096	1,531,079	845,321
South America: Chile, crude potassium nitrate	b	b	b	b	b	b
Europe:						
France (Alsace), crude potassium salts.	2,945,346	500,700 ^c	852,733	145,000 ^c	3,000,000	510,000 ^c
Germany, crude potassium salts:						
Carnallite ^d	15,861,933	1,925,530	b	b	b	b
Kainite, sylvanite, and hartsalz.						
Spain, crude potassium salts.	675,836 ^e	116,000 ^f	710,496	113,700 ^f	572,329 ^g	
Asia:						
India (British), nitrate of potash.	b	b	b	b	b	b
Korea (Chosen), alunite.	12,000	b	b	b	b	b
Palestine, crude potassium salts ^h	105,050	52,500	b	b	b	b
Australia, alunite.	1,598	b	22,616	b	b	b
Total (estimated).		3,410,000		1,410,000		2,240,000

^a In addition to countries listed China, Eritrea, Iran, Italy, Poland, and U.S.S.R. are reported to produce potash salts, but statistics of production are not available.

^b Data not available.

^c Equivalent K_2O content estimated at approximately 17 per cent.

^d Includes some natural kieserite.

^e Salable.

^f Extracted from waters of Dead Sea.

^g Unofficial estimate.

^h January to September, inclusive.

Other Silicates. Many other silicates are potential sources of potash and some of them exist in billions of tons. Feldspar, shales, slates, sericite, and others have been investigated. Potash shales occur in large quantities in Georgia and are reported to contain 7 to 9 per cent potassium oxide. Similar shales are present in Illinois. The problem of the extraction of potash from silicates is much the

* See Leucite, pages 278 and 279.

same for all minerals. Many patents have been issued covering processes for this operation. Costs have been so high that competition with soluble salts has been impossible.

Potash was recovered from cement-kiln flue dust in a number of operations during the First World War. One cement mill continues this practice in Maryland. The product recovered is a potassium sulfate of low purity. It is sold directly for agricultural use.

Prices. In 1950 muriate was quoted at 37 to 45 cents per unit fob mines, basis 60 per cent K_2O ; and manure salt 20 cents per unit, basis 22 per cent K_2O .

World Production. World production as reported by the U.S. Bureau of Mines is shown in Table 5.

Reserves. According to Dolbear,⁸ known reserves of potash in brines and soluble salts in the United States amount to 107 million tons of potassium oxide. Of this tonnage 73 million tons is estimated to be recoverable. Distribution is shown in Table 6. In addition, there are several hundred million additional tons in unexploited areas and in minerals not considered commercial at this time.

TABLE 6. RESERVES IN PRESENT OPERATIONS, TONS K_2O

State	Gross reserves	Recoverable reserves
New Mexico.....	85,963,000	58,000,000
California.....	20,000,000	14,000,000
Utah (brines).....	1,000,000	1,000,000
Total.....	106,963,000	73,000,000

Utilization. About 90 per cent of the potash produced in the United States is used for fertilizer. For certain crops and certain types of soils, potash seems to be necessary if the fertility and productivity of the soil are to be maintained. In this country the cotton crop needs and has consumed more potash than any other single crop. Other crops that show the greatest needs for potash are potatoes, tobacco, and citrus fruits. The economic advantage of using potash fertilizers depends upon the nature of the soil and of the crop to be grown, the cost of the potash, and the price received for the crop. Potash in fertilizers serves a distinct purpose for which no other fertilizer materials, such as phosphates or nitrates, can be substituted.

In 1946 around 75,000 tons of potash chemicals were sold. The most important salts are the carbonate, chlorate, nitrate, bichromate, cyanide, ferricyanide, caustic potash, and elemental potash; but over 40 potash salts are used by industry. The chief uses are in soap, glass, matches, explosives, tanning, dyeing, metallurgy, electroplating, and photographic chemicals.

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PUMICE AND PUMICITE

Definition. *Pumice* is a highly vesicular or cellular glassy volcanic lava, usually rhyolitic in composition. Its cellular structure is due to the expansion during cooling of steam and gases contained in the molten lava.

Pumicite, or volcanic ash, is a more or less finely divided powder or dust made up of small, sharp, angular grains of volcanic glass of about the same composition as pumice. It is formed by the violent and explosive eruption of volcanoes, which throw out this dust in great clouds. Ultimately, the dust settles, often many hundreds or thousands of miles from its original source, and forms beds of pumicite.

Santorini or *Santorin* earth is a variety of pumice mined on Santorin Island (Greece), used in making pozzuolana cement.

Composition. Pumice and pumicite usually have about the same composition as normal rhyolites (highly siliceous natural volcanic rock), but may tend toward the composition of obsidian (natural volcanic glass high in iron and other bases). It has been stated¹⁵ that good Italian pumice from the Island of Lipari has about the following composition: silica (SiO_2), 73.70 per cent; alumina

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(Al_2O_3), 12.27 per cent; potash (K_2O), 4.73 per cent; soda (Na_2O), 4.52 per cent; iron oxides, 2.31 per cent; water, lime, etc., 2.47 per cent; total, 100 per cent. Table 1 shows the normal range in composition.

General Description. Pumice is found near active or geologically recent volcanoes, in solid blocks or fragments down to sand size, or in mixtures of fines and moderately coarse pieces, generally nearly white or light gray in color. These blocks, when dry, will float on water, that is, their apparent specific gravity is less than 1. The cell structure varies from coarse to very fine. The degree of coherence varies greatly from strong and solid to friable and almost pulverulent.

TABLE 1. ANALYSES OF PUMICE AND PUMICITE

	1	2	3	4	5	6	7	8	9
SiO_2	67.39	76.91	61.07	71.80	73.44	68.823	68.68	73.91	73.70
Al_2O_3	15.99	12.18	17.55	15.48	13.68	13.316	{ 12.69	13.30	12.27
Fe_2O_3	0.56	0.48	2.13	0.80	0.98				
FeO	1.99	0.92	4.13	.....	.....	0.192	1.17		
MgO	0.77	0	2.26	0.53	0.57	0.960	1.14	0.37	0.29
CaO	1.63	0.92	6.28	1.42	1.24	3.231	1.11	0.54	0.65
Na_2O	4.74	4.17	3.50	5.89	5.91	3.572	{ 1.32	3.63	4.25
K_2O	4.80	3.15	0.98						
H_2O	2.06	0.90	1.60	4.08	4.18	.....	7.99	1.01	1.22
TiO_2.....	.....	0.18	0.47						
Miscellaneous.....			0.40	.....	.....	2.130*			
Organic matter.....				.....	.....	8.223			
Total.....	99.63	99.81	100.37	100.00	100.00	100.447	100.73	99.40	99.82

* SO_3 .

1. Pumice, Mono Lake, Calif. Melville, analyst. See *U.S. Geol. Survey, Bull.* 150, p. 148.

2. Pumice, Katman Volcano, Alaska, 1912 eruption. G. Steiger, analyst, U.S. Geol. Survey.

3. Pumice, Mount Pelée, May, 1902, eruption. See Diller: *Natl. Geographic Mag.*, Vol. 13, p. 285.

4. Pumicite, Orleans, Harlan County, Nebr. Analysis by University of Nebraska. See *Nebr. Geol. Survey*, Vol. 4, pt. 27, p. 398.

5. Pumicite, Custer County, Nebr. Analysis same as 4.

6. Pumicite from 7 miles south of Okemah, Okla. Aurin, analyst, Geol. Survey, Okla.

7. Pumicite from Gallatin County, Mont. ROWE, JESSE PERRY, *Univ. Montana, Bull.* 17, 1903, pp. 9-10.

8. Pumice, Mount Shasta, Siskiyou County, Calif. Analysis by Commercial Electrolytic Corp. for Brand and Stevens.

9. Pumice, Lipari. Authority, Mitchell. Quoted in Tariff Brief by Brand and Stevens before Committee on Ways and Means, House of Representatives, Jan. 10, 1921.

Pumicite occurs as a powder, varying from coarse to fine, usually nearly white or light gray in color, in irregular bedded deposits; sometimes slightly coherent. These deposits may vary in thickness from a few inches up to as much as 100 ft, but commercial deposits usually average from 6 to 10 up to 20 or 25 ft in thickness. The beds are not necessarily close to their volcanic source, but often are distant several hundred or even 1,000 miles from it. In general, the coarsest grains are found nearest the volcanic source and the finest dust on the extreme

edges of the zone. The pumicite is often mixed in varying proportions with sand, clay, silt, or even diatomaceous earth and is sometimes partly cemented with calcium carbonate. The beds of pumicite are usually overlain with a varying thickness of sand, clay, loess, or other overburden.

Physical Properties. *Hardness*, varies, but is usually about 6 for individual grains. *Specific gravity*, true (for pumicite and ground pumice), about 2.5; apparent (for dry block pumice), less than 1. *Color*, usually light gray or white, also bluish gray to dark gray, reddish, yellowish, and brownish. *Streak*, white. *Luster*, earthy or sometimes silvery; under microscope, glassy or vitreous. *Cleavage*, none. *Fracture*, irregular; under microscope pumicite resembles broken glass. *Transparency*, translucent. *Tenacity*, brittle to pulverulent.

Occurrence. The modes of origin and occurrence of pumice and pumicite have been already briefly noted. Geographically, pumice and pumicite are widely distributed and are found all over the world in areas of certain types of volcanic activity. Commercial deposits, however, are not nearly so widespread in occurrence, for in many cases the material does not possess the desired physical properties. This is particularly true of block pumice, and such material of desirable grade is produced in very few localities. Pumicite of good grade, however, is very widely distributed.

Deposits of pumice suitable for making lightweight concrete aggregate are abundant in many areas in the far-western states; but block pumice suitable for use as natural blocks for abrasive purposes is of uncommon occurrence. A few deposits are known in California and deposits are reported in Oregon and Arizona. But the most important and, in fact, almost the only large deposits of high-grade block pumice are on the island of Lipari, near the north coast of Sicily and about 40 miles from the Italian mainland. Many other deposits are known and some of them have been worked in a small way, but no material from such deposits has been so satisfactory as that from Lipari.

Pumicite deposits have been worked chiefly in the United States and little information is available on foreign deposits. Pumicite cannot, in most cases, be substituted for lump pumice.

United States. Until 1941 the production of pumicite far exceeded that of pumice, but just before the Second World War the use of pumice as a concrete aggregate began to be of importance in the far-western states. During the war production dropped, but with the intensified building program at the end of the war and with the shortage of structural steel, which made the use of lightweight aggregates financially worth while, pumice production increased very rapidly.

California produces both pumice and pumicite. In 1946 commercial production came from the following counties, more or less in order of production: Madera, Siskiyou, Inyo, Modoc, Contra Costa, Mono, Calaveras, and Kern. High-grade block pumice, which is sawed into bricks and blocks for abrasive use, is produced at Glass Mountain, near Tionesta, Siskiyou County. Water-deposited pumicite is produced at Friant, 20 miles north of Fresno.

Idaho. In 1946 Idaho jumped from a very unimportant producer to the largest producer of pumice in tonnage, but far below California in value. Nearly all of its production was for concrete aggregate.

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New Mexico was the third largest producer in 1946, with operating deposits of pumice near Grants, Santa Fe, and elsewhere. Extensive deposits of both pumice and pumicite are reported at numerous localities.

Kansas is by far the largest producer of pumicite, although at one time *Nebraska* held that position. *Kansas* pumicite, described in detail by Landes,¹² occurs in greatest abundance near the 100th meridian. Deposits vary from a few inches to 20 ft thick and may be covered with as much as 20 ft of overburden. In the poorer deposits the pumice may be mixed with diatomite, silt, or calcareous matter. Centers of production have been in Meade, Norton, Osborne, Ellsworth, and Haskell counties, but occurrences are widespread. Most of the production has been for abrasive soaps and soap powders such as Old Dutch Cleanser.

*Nebraska*¹ has very extensive deposits of pumicite, similar to those of *Kansas*, but many deposits are of too low grade to be commercial. Deposits have been operated in Furnas, Lincoln, Harlan, Jefferson, Custer, Greeley, Holt, Antelope, and other counties.

*Washington*⁵ has numerous large deposits of both pumice and pumicite, and commercial production is beginning to be of importance.

Other states which have been producers of either pumice or pumicite in recent years are Oregon, Colorado, and Texas, but deposits are known in Nevada, Utah, Arizona, Wyoming, Oklahoma, South Dakota, and probably other far-western states.

Italy.³ Before the Second World War Italy was an important producer of pumice both on the mainland (Campania and Rome mining districts) and on the island of Lipari. Of the total Italian production of 146,522 tons in 1939 about 35 per cent was from the mainland, used chiefly as a building material, and 65 per cent from Lipari, largely abrasive material for export. The Lipari deposits cover several square miles in the northeastern part of the island and are reported to contain at least 500 million tons. The pumice, which occurs in unconsolidated bedded deposits in rugged terrain, is removed by hand methods, mostly from open cuts. High-grade block pumice, a very small part of the output, is recovered from underground mines.

The crude pumice is sorted, cleaned by screening or water-floating, and graded by size and quality. Standard sizes and grades are: lump, 2 in. and over; pezzame, $\frac{3}{4}$ to 2 in.; chips, $\frac{1}{4}$ to $\frac{3}{4}$ in.; Lapillo powder, $-\frac{1}{4}$ in.; and waste (obsidian, lava, subgrade pumice). Lump pumice is graded by density, color, and texture. Best grades are light colored, fluffy, of very low apparent density, and of such texture that the thin cell walls are clearly distinguishable. Lower grades are denser and darker in color and may contain mineral impurities. Lump pumice is prepared for market by rounding all edges and corners by hand filing or by tumbling in iron cylinders. Ground pumice is made by grinding, screening, and air floating pezzame (better grade) and Lapillo powder. Pezzame is dried, in the sun or in coal-fired driers, to less than $7\frac{1}{2}$ per cent water (to ensure proper grinding). Grinding is done in stone disk mills or in stone rolls. As shipped pezzame runs 80 to 90 cu ft per metric ton; and ground pezzame, 30 to 40 cu ft per ton. Before the war about half of the pezzame tonnage was ground locally and the balance shipped to the United States and the United Kingdom for grinding.

Other Countries. Extensive deposits of pumicite occur in *Canada* in Saskatchewan and British Columbia. Pumicite is produced in *New Zealand*. *Japan* produces pumice for lightweight concrete aggregate. Pumice deposits are reported in *Austria*, and a crudely sorted mixture of pumice and pumicite has been mined in the Rhine Valley in *Germany*, chiefly as a building material. Undoubtedly workable deposits of pumice and pumicite occur in many other countries and development only awaits suitable markets.

Production and Consumption. Tables 2 and 3 and Fig. 16 show the trends of the United States production of pumice and pumicite in recent years.

Normal prewar imports averaged 8,000 to 10,000 tons per year, most of which was crude Italian pumice for grinding. After the war imports were resumed in 1946 and shipments reached nearly 6,400 tons, of which over 80 per cent was crude, valued for import duties at about \$11 per ton.

TABLE 2. PUMICE AND PUMICITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948

Year	Short tons	Value
1944	88,757	\$ 704,110
1945	157,011	1,051,037
1946	319,883	1,585,753
1947	442,552	2,021,880
1948	607,746	2,501,906

TABLE 3. PUMICE AND PUMICITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value
California.....	31,409	\$245,898	75,238	\$481,664	89,181	\$755,570
Colorado.....					600	1,200
Idaho.....			*	*	108,847	163,515
Kansas.....	43,034	163,538	47,484	187,651	35,466	105,084
Nebraska.....	6,083	51,043	6,764	59,735	4,772	45,900
New Mexico.....	*	*	*	*	62,623	432,890
Oregon.....	*	*	*	*	3,004	12,532
Texas.....	*	*	584	11,680	805	13,054
Washington.....	783	8,705	4,414	36,045	14,585	56,008
Undistributed*	7,448	234,926	22,527	274,262		
	88,757	\$704,110	157,011	\$1,051,037	319,883	\$1,585,753

* Figures that may not be shown separately are combined as Undistributed.

Markets and Prices. Italian pumice is imported into the United States, chiefly by a few companies in New York City. About 80 per cent of the imports are in the form of "pezzame," or pumice chips, which are ground to a powder in plants in the vicinity of New York. This powder is bolted and sold in four sizes,

namely, F, FF, FFF, and FFFF, and is usually sold by these companies directly to consumers, but some of it is handled through brokers and jobbers.

Estimates differ as to the amount of pumice used in the United States in lump form. These estimates range from 100 to 400 tons per year.

Pumicite is mined largely by the companies that use it in the manufacture of household cleansers, soaps, polishes, etc. A smaller amount is produced independently and marketed either directly to consumers or through jobbers. It is generally conceded that domestic pumicite cannot be substituted, for most purposes, for high-grade pulverized Italian pumice. It is apparently not so pure and uniform and does not have so high an abrasive efficiency.

Pumice for concrete aggregate is either used by the producers or shipped in bulk to contractors and makers of concrete block and tile. Since it is a low-priced, bulky product it cannot stand high transportation costs, and markets are limited to within a fairly short shipping radius.

In 1946 the average value of all pumice and pumicite produced in California was about \$6 per ton, fob producing point. In 1947 crude pumice aggregate from Siskiyou County, Calif., sold for \$2 per cubic yard fob cars; pumice crushed and screened through $\frac{1}{4}$ in. sold for \$3 per cubic yard. Ground pumice, in barrels, in New York and Chicago, is commonly quoted from $2\frac{1}{2}$ to $4\frac{1}{2}$ cents per pound; lump pumice, from 5 to $7\frac{1}{2}$ cents per pound.

Utilization. The largest use for pumice today is for lightweight concrete aggregate. The crude pumice is usually excavated from open cuts, dried, crushed (if necessary), and screened into various commercial sizes, most of which are $\frac{1}{4}$ in. or finer. Carithers,⁵ from whom the following is taken in part, summarizes the advantages of pumice as a concrete aggregate.

Pumice, when employed as a lightweight aggregate in precast masonry units or in poured concrete in place of sand and gravel, considerably reduces the weight of the material, and concrete that commonly weighs from 140 to 150 lb per cu ft when made in the conventional manner can be made to weigh as little as 50 lb per cu ft. This lightness in weight reduces the dead load on steel framework in large buildings and bridges and permits important savings in steel. The lighter units are easier to handle and install and cost less to transport. Strength of pumice concrete usually varies inversely with lightness in weight. Blocks that have a low apparent density about 60 to 70 lb per cu ft have a crushing strength of from 600 to 1,000 lb per sq in. Denser blocks are proportionately stronger.

Other advantages of pumice concrete are heat and sound insulation, fire resistance, ease of cutting and shaping, and ability to hold nails and screws. Thermal-insulation efficiency varies inversely with the density. Pumice blocks of low density have a thermal conductivity one-third to one-ninth that of ordinary concrete and one-third to one-sixth that of common brick.

Ground pumice and pumicite are used as admixtures in concrete, replacing a portion of the cement without impairing the strength. For example, the U.S. Bureau of Reclamation specified the use of 20 per cent pumicite by weight with the cement to be used in the Friant Dam in California. Here the specifications required that 98 per cent pass a 325-mesh screen; apparent density, 40 to 47 lb per cu ft; specific gravity, 2.4.¹⁶ Several manufacturers use ground pumicite, up

to 15 or 20 per cent, mixed with cement clinker and gypsum, to make pozzuolanic cements.

Barbour¹ notes that "pozzuolana was the material used in the famous Roman walls, aqueducts, and historic buildings, and that the Pantheon, built of it about 2,000 years ago, stands today without a crack. This remarkable cement was made of volcanic dust found around Vesuvius, especially of that found near the town of Pozzuoli, which gave the name pozzuolana to the cement."

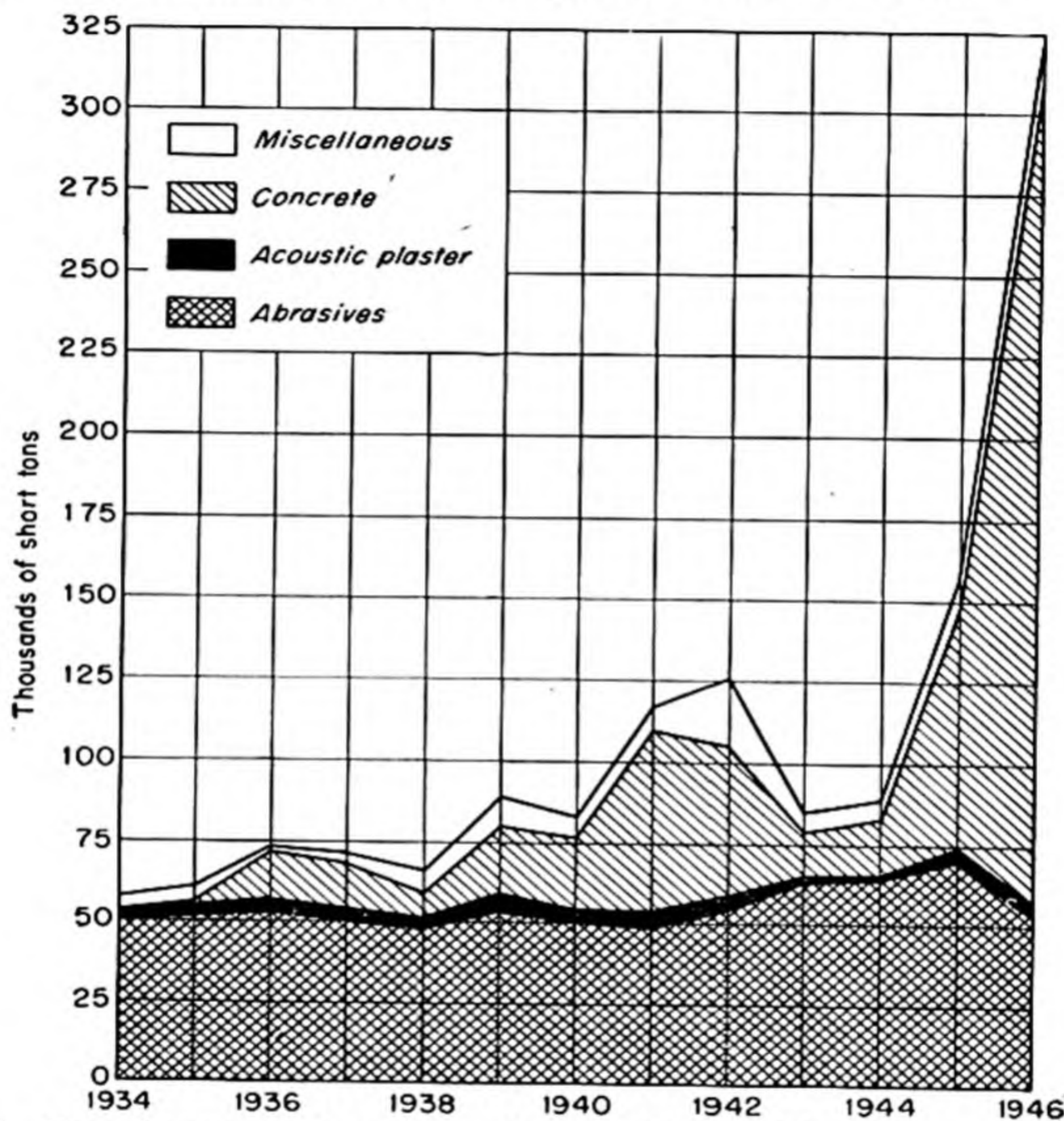


FIG. 10. Uses of pumice and pumicite sold or used in the United States, 1934 to 1946.

Fairly coarse, screened pumice is used as loose-fill heat insulation in floors, walls, and ceilings in several types of buildings, including cold-storage warehouses. The thermal conductivity of loose pumice ranges from 0.5 to 1.0, compared with mineral wool of 0.26 to 0.4 and wood shavings of 0.4 to 0.5.

Pumice is used in acoustic tile and plasters, as an absorptive packing material, and as a carrier for catalysts in some chemical industries.

Pure lump pumice is used as an abrasive; in silver plating and by lithographers for polishing various metals, such as copper and silver, before plating; for rubbing

PUMICE AND PUMICITE

down wood and metal surfaces and paint and varnish finishes by manufacturers of furniture, pianos, phonographs, and other musical instruments, coaches and automobile bodies; for rubbing down and polishing, by manufacturers of cutlery, surgical instruments and other fine tools; by metal spinners, art metal workers, etc.; and for cleaning and polishing stone and glass. A small amount of fine lump pumice is used as a toilet article for removing cuticle, stains, etc.

Block pumice has been used to some extent as a building stone in localities where it is produced.

Ground pumice is used in cleaning, scouring, and polishing compounds; in tooth pastes and powders; as an abrasive in rubber erasers; for many uses similar to those listed under lump pumice and pumicite; and for abrading and polishing hard rubber, fiber board, etc.

Pumicite finds its largest use in making cleansing compounds such as Old Dutch Cleanser, manufactured by the Cudahy Packing Co., which are chiefly pumicite with small amounts of soap powder, soda ash, or other ingredients. It is also used in abrasive hand soaps, mechanics' paste soaps, silver and other metal polishes; in dustless sweeping compounds (which consist primarily of sawdust soaked in paraffin oil to which salt has been added to render it hygroscopic); as a filler for paint; for some of the uses noted under lump and ground pumice; it has been used to a limited extent for heat insulation around boilers, pipes, etc., and for cold insulation in refrigerators, etc.; to a small extent for filtering oils, etc.

TABLE 4. PUMICE AND PUMICITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY USES

Use	1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value
Abrasive:						
Cleansing and scouring compounds and hand soaps.....	57,833	\$375,310	63,704	\$ 434,928	52,085	\$ 386,593
Other abrasive uses.....	6,094	136,753	7,307	229,212	2,369	112,694
Acoustic plaster.....	938	29,144	3,693	78,278	4,342	139,871
Concrete admixture and concrete aggregate.....	17,511	90,136	72,901	176,920	248,247	607,695
Other uses*.....	6,381	72,767	9,406	131,699	12,840	338,900
Total.....	88,757	\$704,110	157,011	\$1,051,037	319,883	\$1,585,753

* Insecticide, insulation, brick manufacture, filtration, solvents, plastics, paint filler, absorbents, and unspecified.

Other uses for pumicite and pumice that have recently been developed or are in the experimental stage are as a filler in prepared roofing, as an inert carrier for insecticide dusts, as a rubber filler, as an asphalt filler, and as an ingredient in ceramic bodies and glazes and enamels.

As a lightweight concrete aggregate pumice competes with perlite, vermiculite,

diatomite, and artificially expanded clays, slates, shales, slags, and other materials.⁹

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PYROPHYLLITE

Composition. Pyrophyllite is a hydrous aluminum silicate, $H_2Al_2(SiO_3)_4$ or $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$. Theoretical composition: Al_2O_3 , 28.3 per cent; SiO_2 , 66.7 per cent; H_2O , 5.0 per cent. Commercial pyrophyllite nearly always contains considerable sericite or quartz or both as indicated in Table 1.⁶

* See also bibliography under Perlite.

PYROPHYLLITE

The Stem sample is from a deposit of nearly pure pyrophyllite. As noted, quartz and sericite are the most abundant accessory minerals. Chloritoid varies from infrequent to abundant. Pyrite, chlorite, feldspar, hematite, and magnetite are common but minor accessories. For some uses quartz and sericite are objectionable impurities; but for other uses, such as in ceramics, they may even be advantageous.

General Description. Pyrophyllite (also known as agalmatolite*) is a very soft mineral resembling talc, usually occurring in white, yellowish or light-pink or gray compact or foliated masses, less commonly in radial fibrous aggregates.

TABLE 1. ANALYSES OF NORTH CAROLINA PYROPHYLLITE

	Hemp	Hemp	Staley	Glendon	Stem	Theoretical
SiO ₂	79.25	74.40	76.27	77.61	65.16	66.7
Al ₂ O ₃	16.23	19.07	19.04	17.59	28.85	28.3
Fe ₂ O ₃	0.09	0.17	0.13	0.11	0.60	
TiO ₂	0.11	0.18	0.42	0.00	0.05	
CaO.....	0.08	0.00	Trace	0.34	0.00	
MgO.....	0.02	0.10	0.05	0.22	0.08	
Na ₂ O.....	0.20	0.22	Trace	0.12	0.03	
K ₂ O.....	1.64	2.77	0.04	0.40	0.05	
Ignition loss.....	2.35	2.98	3.90	3.51	5.13	5.0
	99.97	99.89	99.85	99.90	99.95	100.0

Physical Properties. *Hardness*, 1 to 2.5. *Specific gravity*, 2.8 to 2.9. *Melting point*, high. *Index of refraction*, 1.552 to 1.600. *Color*, white, yellowish, silvery gray, pinkish, greenish, and brownish; also mottled. *Streak*, white. *Luster*, pearly, greasy, or dull. *Cleavage*, foliated or uneven fracture. *Transparency*, opaque to translucent. *Tenacity*, slightly sectile to brittle, slightly flexible.

For more detailed data on physical and chemical properties see Refs. 2, 3, and 6.

Occurrence. Nearly all the domestic production of pyrophyllite comes from North Carolina, where the principal deposits are in Moore (at Hemp and Glendon), Randolph (at Staley), and Alamance (at Snow Camp) counties. At Stem, Granville County, is a small deposit of nearly pure, radial, crystalline material. Other deposits of lesser importance are reported at Chesterfield, S.C.; Graves Mountain, Lincoln County, Ga.; Troy, Montgomery County, N.C.; and Quartzite, Ariz.

In *North Carolina* the pyrophyllite occurs in irregular lenses, 100 to 500 ft wide by 700 to 1,500 ft or more in length. Maximum depth is unknown, but drill holes 500 ft deep have failed to bottom the ore. Since most of the impurities are concentrated along the walls, workings are usually confined to a width of 50 to 150 ft in the center of the deposit.

* Agalmatolite and pagodite have been used to refer to compact pyrophyllite. Dana states that Chinese agalmatolite is in part pinite and in part steatite or talc. Pinite is a hydrous silicate of alumina and the alkalis, possible in part agalmatolite.

In *California* a deposit of pyrophyllite was reported to be in production in 1947, 17 miles north of Laws on the west slope of the White Mountains in Mono County. A working deposit is also reported near Rancho Santa Fe, San Diego County.

A pyrophyllite deposit was discovered in *Pennsylvania* in 1947. It is located in Huntington Township, Adams County, just north of the hamlet of Gargol. It appears to be a hydrothermal replacement of volcanic rocks and resembles the deposits of North Carolina. The extent and quality of the material are being determined by exploratory drilling.

In *Newfoundland* deposits of pyrophyllite have been worked spasmodically since about 1903. They occur about 6 miles south of Manuels on Conception Bay, Avalon Peninsula, on the southeastern part of the island. Here the pyrophyllite occurs in irregular bands and lenses in pyrophyllite-quartz schist, requiring hand sorting. While reserves are reported to be large the average content of the ore is low, 30 to 50 per cent, and successful exploitation would seem to be difficult.

*Japan*⁵ has been a substantial producer for many years. Total production is estimated at 5 million metric tons. Since there is practically no talc in the country pyrophyllite has been used as a substitute in many industries. There are reported to be 55 active mines, 80 per cent of which are located in the Okayama Prefecture. Maximum production of 454,533 metric tons was reported in 1939. The industry declined during the war years but is expected to regain its former position. The mineral is mined by hand with crude equipment, ground in small mills, and washed. The ground material is allowed to settle in long troughs so that the finest pyrophyllite floats the greatest distance from the feed point. Removal of coarse impurities and some sizing of final product are thereby attained. The entire operation is primitive and accompanied by a very high percentage of waste. Sixty per cent of the output is consumed in the manufacture of fire-brick; the remainder is used in the production of porcelain and mortar and as clay.

Mining and Milling. Pyrophyllite is so soft, particularly in the upper, weathered zones, that it drills and breaks very easily. Deposits are worked by open-pit, by glory-hole, and by regular underground mining methods. Careful mining and hand selection are necessary to minimize quartz and sericite content and reject iron-stained and other impure material.

The ore may be milled after simple air drying or it may be dried in indirect-heat rotary driers. After crushing, the ore is ground in Raymond roller mills with air separation or in silex-lined Hardinge conical pebble mills in closed circuit with Gayco air separators. Finished products, from 80 to 325 mesh, are shipped in bulk in boxcars or packed in bags.

Production and Uses. Originally pyrophyllite deposits were developed to make fillers and dusting agents used for the same purposes as and competitive with talc. Because of the high grit content and poor color of most of the early material important tonnage markets were hard to develop. About 1927 the R. T. Vanderbilt Co. began the introduction of pyrophyllite as a ceramic raw material and a few years later patented a floor and wall tile body composition using pyrophyllite as an essential material. Since that time there has been a great deal of

PYROPHYLLITE

ceramic research on this material, studying its properties and suggesting many uses in whitewares, porcelain, refractories, and other ceramic products. One company produces a blend of feldspar and pyrophyllite which it sells to the glass industry as a source of alumina. Demand increased greatly, and by the end of 1937 six mills were reported to be grinding pyrophyllite in North Carolina; in 1940, however, there were only three producing companies.

More recently the greatly increased use of insecticide dusts has further stimulated the demand for pyrophyllite. Other uses are more or less identical with those for talc and are noted on page 542.

TABLE 2. SALES OF NORTH CAROLINA PYROPHYLLITE, 1942 TO 1946

Year	Crude		Ground		Total	
	Tons	Value	Tons	Value	Tons	Value
1942	.....	.....	.....	.....	53,669	\$414,816
1943	5,432	\$34,306	56,710	\$460,484	62,142	494,791
1944	5,683	52,343	60,560	504,739	66,243	557,082
1945	6,215	38,166	71,379	613,034	77,594	651,200
1946	10,716	85,002	85,835	913,301	96,551	998,303

Prices. Because of its resemblance to talc in properties, occurrence, and production costs, pyrophyllite is sold in approximately the same price range.

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QUARTZ AND SILICA

The minerals that consist essentially of pure silica— SiO_2 , silicon dioxide—are among the most abundant in the earth's crust. Of these minerals quartz is the most common. In abundance and economic value the types and varieties of quartz range from the worthless deposits of desert sand to the exceedingly scarce and valuable flawless rock crystal used for oscillator plates in radio transmitters and other electrical devices. Industrially, with but few exceptions, these forms and types of quartz fall into a few well-defined groups based on physical properties, scarcity, and general type of use. These groups are as follows:

Quartz Forms Based on Industrial Use.

1. Rock crystal
 - a. Piezoelectric quartz for oscillator plates
 - b. Melting quartz for fused quartz
 - c. Cutting quartz for semiprecious stones
2. Quartz family minerals, semiprecious stones
 - a. Crystalline varieties, such as amethyst and citrine quartz
 - b. Cryptocrystalline varieties, such as agate, carnelian, and jasper
3. Silica

Lower grades, such as massive, opaque quartz, quartzite, and ground sand, used for chemical and industrial purposes
4. Sand and Gravel
5. Stone

Sandstone and quartzite used for structural purposes
6. Silica abrasives

Grindstones, pulpstones, whetstones, etc.

Of these types and varieties only the first three will be treated in this discussion. Separate sections are devoted to sand and gravel, stone, and abrasives, as well as to tripoli. The hydrous or opalescent varieties, diatomite and opal, are also covered in separate sections. There is some overlapping in this classification, such as the use of agate for bearings in balances and the use of high-grade sand for making glass and silicon carbide, but in general it corresponds to commercial usage and to the grouping used by the U.S. Bureau of Mines in collecting statistics.

QUARTZ

Composition. Quartz is silica, or silicon dioxide (SiO_2): Si, 46.7 per cent; O_2 , 53.3 per cent.

General Description. Quartz is a very common, hard, brittle mineral rarely having cleavage, but having a conchoidal fracture, and occurring in a great variety of forms and colors. When pure and crystallized it occurs as well-formed hexagonal prisms, terminating in apparently hexagonal pyramids. Its various forms may be divided into three main classes: (1) crystalline varieties, (2) cryptocrystalline or chalcedonic varieties, and (3) clastic varieties.

QUARTZ AND SILICA

Of the crystalline varieties the commonest form is ordinary quartz crystal, which, when clear and colorless, is known as *rock crystal*. Other well-known varieties are: *smoky quartz* (sometimes known as *cairnngorm*); *citrine quartz* (yellow in color); *amethyst* or *amethystine quartz*; *rose quartz* (usually massive); *rutilated quartz* (quartz crystal containing fine, interlaced needles of rutile); *milky quartz* (white and translucent to opaque); *ferruginous quartz* (containing brown or red limonite or hematite, opaque); *cat's-eye* (grayish, brownish, or greenish and opalescent due to included fibers of other minerals); *aventurine* (opaque, included flecks of mica, hematite, etc.).

Chalcedony, the type material of the cryptocrystalline group, is opaque, translucent to transparent, has a greasy luster, and occurs in a variety of colors: white, gray, blue, brown, and black. *Agate* is usually banded and varicolored (frequently artificially colored). Other varieties are: *carnelian* or *sard* (reddish chalcedony); *onyx* (parallel banded chalcedony usually alternating black and white); *sardonyx* (like onyx but brown and white); *chrysoprase* (apple-green chalcedony, color due to small percentage of nickel salt); *heliotrope*, *plasma* or *bloodstone* (bright- or dark-green chalcedony spotted with red jasper); *prase* (dull leek-green); *jasper* (opaque and usually red, due to iron oxide); *flint* (usually as nodules with white coating of chalk, gray, gray-brown, or brownish black, translucent to opaque, prominent conchoidal fracture). *Buhrstone* (burrstone) is a white, gray, or yellowish, tough, chalcedonic stone, containing numerous small cavities due to dissolving of calcareous fossils.

The clastic varieties include: *sand* and *gravel*; *sandstone* (sand cemented together with silica, calcite, iron oxide, clay, etc.); *quartzite* (metamorphosed sandstone with silica cement in which original grains are usually not easily identified); *itacolumite* (a flexible sandstone containing some mica).

Physical Properties. *Hardness*, 7. *Specific gravity*, 2.6 to 2.66. *Index of refraction*, 1.544 to 1.553. *Color*, all colors and colorless (many colors disappear on heating). *Streak*, white. *Luster*, vitreous to greasy. *Cleavage*, none, conchoidal fracture. *Transparency*, transparent to opaque. *Tenacity*, brittle to tough. *Behavior on heating*, at 573°C low-temperature quartz inverts to high-temperature quartz; at about 870°C this quartz begins to invert to tridymite (specific gravity 2.28 to 2.33) or cristobalite with increase in volume; it begins to soften at about 1500°C and melts at about 1710 to 1756°C. *Solubility*, insoluble in all acids except hydrofluoric.

Occurrence. Silica is one of the principal components of the earth's crust and, in its various forms, is universally distributed. Of the most common varieties commercially important, quartz is mined chiefly from pegmatite dikes, from veins, or from unconsolidated beds of residual clays (Brazilian rock crystal); flint, as nodules in chalk deposits (England, France, Belgium, etc.) and as beach pebbles; sand and gravel, as stream, glacial, or marine deposits.

Rock Crystal or Crystal Quartz, Radio Grade. The most important use for crystal quartz depends upon a property found in few natural minerals—the piezoelectric effect. When a thin wafer of quartz, cut at a critical angle with the vertical axis, is subjected to pressure, a minute charge of electricity is generated. Conversely, when an electric current is applied to such a wafer, a minute amount

of bending takes place. This property, known as the piezoelectric effect, is used in a variety of electrical equipment but its most important application is for frequency control in radio transmission, radar, and other electronic devices. While over 175 substances have been reported as having piezoelectric properties to some degree, they include only a few minerals, crystal tourmaline, nepheline, and berlinite (a hydrous aluminum phosphate analogous to turquoise) being the most promising. No deposits of these minerals suitable for this work, however, are known. Most artificial compounds have disadvantages of easy solubility, chemical instability, softness, or other qualities that either unfit them for frequency-control use or decidedly limit their use. For many reasons quartz is the ideal material. But crystal quartz of the proper quality is exceedingly scarce and relatively very large quantities are needed, especially in wartime. Over 4 million lb of radio-grade quartz was required between January, 1942, and V-J Day.²⁰

For piezoelectric use quartz must be water clear, perfectly transparent, and free from all visible impurities or flaws, with a minimum weight of at least 100 g; it must have a length parallel to the vertical axis of at least 2 in., and a diameter perpendicular to the vertical axis of at least 1 in. Quartz of this size must have at least one identifiable crystal face, though pieces of 2,000 g or larger may be optically oriented commercially without any crystal faces. In addition twinning, either optical or electrical, unfits quartz for this use. Since few natural quartz crystals are found without either or both types of twinning in some portion of the crystal there is a tremendous wastage in the selection and cutting of quartz for this use.

A few uncommercial occurrences of clear quartz (for example, in Arkansas and California) are known in this country, but no important productive sources have ever been found in North or Central America although small shipments have been made from Guatemala and Colombia.

Virtually the only important producer of radio-grade quartz in the whole world is and has been Brazil. While production has come from numerous states about 85 per cent of the total production has been from Minas Geraes, Goiaz, and Baia. Most mines are small and several hundred contribute to the total production. The deposits are of five types: (1) veins and composite lodes, (2) pipes and pockets, (3) blanket deposits, (4) pegmatites, and (5) eluvial and alluvial deposits.* The proportion of usable quartz to total quartz mined is very small.

Madagascar is a small producer of high-grade quartz, largely from rock deposits about 200 miles south of Tananarive. In 1947 their exports were as follows:

	Kilograms
Optical and piezoelectric grades.....	2,688.8
Cutting grade.....	213.4
Fusing grade.....	8,950.0

Total exports went to France except for 50 kg of cutting grade that went to England.

* STOIBEN, RICHARD E., TOLMAN, CARL, and BUTLER, ROBERT D., *Geology of Quartz Crystal Deposits*, *Am. Mineral*, Vol. 30, No. 5, p. 253, May, 1945.

QUARTZ AND SILICA

Table 1 shows United States imports and consumption of radio-grade quartz in recent years. Practically all of this material came from Brazil.

TABLE 1. IMPORTS OF UNCUT QUARTZ CRYSTAL, CONSUMPTION OF RADIO-GRADE QUARTZ, AND PRODUCTION OF PIEZOELECTRIC DEVICES IN THE UNITED STATES, 1944 TO 1948

Year	Imports of uncut quartz crystal*		Consumption of radio-grade quartz, † lb.	Production of piezoelectric devices, †, ‡ number
	Pounds	Value		
1944	2,300,506	\$11,178,643	1,858,000	29,939,000
1945	1,329,798	6,190,621	1,040,000	18,918,000
1946	370,556	2,376,598	172,400	1,744,100
1947	473,788	1,815,468	68,100	1,052,400
1948	1,236,520	4,206,977	61,600	1,225,400

* Includes optical-grade quartz used in production of optical instruments.

† 1942 to 1944, War Production Board.

‡ Includes oscillators, resonators, and other piezoelectric devices.

Specifications for the buying of radio-grade quartz are set by the National Bureau of Standards. Prices paid depend on size and quality and on the percentage of usable quartz in any lot. In 1947 prices ranged from \$1.50 to \$36.95 per pound.

Substitutes for Natural Radio-grade Quartz. Because of the essential nature of our crystal-quartz requirements and the fact that none is produced in this country, strenuous efforts have been and are being made to find acceptable substitutes. Fused quartz cannot be used since it is a glass and has no optical axes, hence no piezoelectric properties. During the Second World War Germany partially developed a process for growing quartz crystals artificially, but commercial success was not attained.¹⁹ Recently it has been announced¹⁸ that the Bell Telephone Laboratories have made quartz crystals superior in quality and performance to natural crystals. Their process is so successful that commercial manufacture in the near future seems possible. Other laboratories are working on the same problem; and work is being done on the commercial synthesis of nepheline, tourmaline, and berlinite.

As a partial substitute for quartz used as filters in coaxial long-distance telephone cable circuits, Bell Laboratories are growing, on a commercial scale, ethylene diamine tartrate (known as EDT) crystals. For this use, prior to the development of EDT, crystals of Rochelle salts and of ammonium dihydrogen phosphate (called ADP) were also grown commercially.

Optical Quartz. Optical quartz is clear rock crystal, usually in pieces of 500 g or larger, suitable for making lenses, prisms, windows, and other components of optical instruments such as quartz refractometers and spectrophotometers. The quartz must be flawless and free from strain and optical twinning, but not necessarily free from electrical twinning. Since large, clear crystals untwinned opti-

cally are exceedingly scarce it is very difficult to get enough material suitable for large lenses to satisfy the demand. For this reason high-grade clear fused quartz of optical quality is being increasingly used as a substitute.

Fused Quartz, Fused Silica, or Vitreous Silica.^{7,9,12} These are terms applied to pure silica glass made by the fusion of quartz crystal or of high-grade glass sand. Clear fused quartz is a water-clear, colorless product made from rock crystal. Vitreous silica, fused silica, or translucent fused quartz are translucent or opaque types made from silica sand. Clear fused quartz is used for optical systems; ultraviolet transmission tubes, cells, and lenses; high-tension electrical insulators; chemical laboratory ware; and production equipment. Translucent and opaque fused silica have lower density, lower mechanical strength, and greater porosity than the clear type and are used for less critical purposes.

Fusing-grade quartz must be as clear and free from all defects and impurities, except twinning, as radio-grade quartz. Hence, carefully sorted discards from radio-grade material have been widely used in the past few years in place of quartz produced primarily for that purpose. Glass sand cannot be used to make clear fused quartz since air films on the surface of the grains and air or gas occluded within the grains cannot escape from the highly viscous glass during manufacture, and a cloudy, translucent or opaque product results.

SILICA

Definition. Silica, or silicon dioxide (SiO_2), occurs in a free state chiefly as quartz, but hydrous silica (amorphous silica carrying a variable amount of combined water, 2 to 13 per cent) occurs as opal, flint, diatomaceous earth, tripoli, and so on. Quartz is found in many forms, the most important of which are as vein quartz; quartzite; sandstone; silica sand and gravel; as crystals or crystalline grains and as masses or aggregates in igneous rocks, such as granites and pegmatites.

Forms of Silica Used Industrially. The various forms in which silica is used commercially (other than the ordinary uses of sand and gravel and structural sandstone) are given below:

1. Massive crystalline quartz (vein or pegmatite)
2. Quartzite
3. Sandstone
4. Flint or chert (massive or as rounded pebbles)
5. Tripoli
6. Diatomaceous earth
7. Silica sand

These types of silica may be used in several different ways:

1. In massive form, roughly broken to size. *Example:* massive quartz for acid-tower packing.
2. In massive form cut to definite shape and size. *Example:* grindstones and diatomaceous earth brick.
3. In original state as pebbles. *Example:* flint grinding pebbles.

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4. In original state as grains. *Example:* glass sand and filter sand.
5. Crushed to coarsely granular form. *Example:* quartz grains for sandpaper.
6. Ground to fine powder. *Example:* ground flint for pottery manufacture and ground diatomaceous earth for polishing powder.

Ground silica appears on the market under the names of silex, flint, and silica, regardless of the original form of the material, as well as under the true mineralogical names.

TABLE 2. QUARTZ (CRUDE, CRUSHED, AND GROUND)* SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948

Year	Crude		Crushed		Ground		Total	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1944	15,222	\$ 35,279	61,823	\$170,325	5,334	\$ 80,874	82,379	\$286,478
1945	24,392	72,392	28,718	93,631	4,654	70,780	57,764	236,803
1946	38,587	107,069	29,228	109,437	5,364	77,346	73,179	293,852
1947	21,940	118,231	62,169	170,254	17,208	136,040	101,317	424,525
1948	41,081	250,184	104,496	374,781	16,284	125,702	161,861	750,667

* To avoid duplication, the ground material shown here is only that ground by the original producers of the crude quartz or by grinders who purchase from small miners not reporting their production.

TABLE 3. QUARTZ (CRUDE, CRUSHED, AND GROUND)* SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value
Arizona.....	67,109	\$206,477	36,044	\$99,113	41,844	\$160,266
California.....						
Washington.....						
Oregon.....						
Maine.....	88	203	4	10	829	7,615
Massachusetts.....	.....	.....	696	6,349		
Virginia.....	75	303	†	†		
Other states‡.....	15,107	79,495	19,558	115,071	30,506	125,871
	82,379	\$286,478	57,764	\$236,803	73,719	\$293,852

* To avoid duplication, the ground material included is only that ground by the original producers of the crude quartz or by grinders who purchase from small miners not reporting their production.

† Included with Other states.

‡ 1944: Maryland, New Jersey, North Carolina, Tennessee, and Wisconsin; 1945: Maryland, New Jersey, North Carolina, South Dakota, Virginia, and Wisconsin; 1946: Maryland, North Carolina, South Dakota, Tennessee, and Wisconsin.

Occurrence and Production. Free silica, in its varied forms, is widely distributed, forming one of the most abundant constituents of the earth's crust; but deposits of commercial value are far less common. Except for such relatively scarce materials as tripoli and flint grinding pebbles, however, most forms of silica are sold for such low prices that economic factors, such as proximity to railroads and to local markets, govern the value of a deposit. Thus, deposits of glass sand may be valueless if located far from supplies of cheap fuel and far from large centers of consumption for glass.

Tables 2 to 5 show the United States production and consumption of several forms of silica.

Prices. Wet-ground, air-floated, 325-mesh material, 92 to 99½ per cent silica was quoted in 1950 at from \$21 to \$40 per ton in bags fob Illinois; dry-ground, air-floated, 325-mesh material, same grade, at \$18 to \$30 per ton.

TABLE 4. GROUND SAND AND SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948, BY STATES

Year	Short tons	Value
1944	558,606	\$3,989,981
1945	533,656	3,709,597
1946	575,888	4,125,398
1947	651,120	5,181,113
1948	702,572	5,814,664

TABLE 5. GROUND SAND AND SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value
Arizona.....	20,872	\$ 208,925	20,610	\$ 225,450	{ 39,401	\$ 215,889
California.....			*	*		
Washington.....			{ }			
Georgia.....	3,090	19,823	7,190	27,858	4,406	25,993
Illinois.....	158,673	1,098,275	144,212	1,003,273	144,753	1,061,946
Massachusetts.....	2,500	21,000	2,350	11,600	2,000	10,000
New Jersey.....	173,551	1,139,818	181,076	1,084,284	105,985	649,828
Pennsylvania.....					*	*
Ohio, Virginia, and West Virginia.....	152,514	1,182,255	142,002	1,102,135	169,710	1,396,151
Other states†.....	47,406	328,885	36,216	254,997	109,633	766,491
	558,606	\$3,989,981	533,656	\$3,709,597	575,888	\$4,125,398

* Included under Other states.

† 1944: Louisiana, Missouri, North Carolina, and Wisconsin; 1945: Missouri, Washington, and Wisconsin; 1946: Missouri, Pennsylvania, and Wisconsin.

Mining and Milling. Methods of mining the various siliceous materials vary widely, depending on the form of the material, the nature and the location of deposits, and the type of product to be made. However, most of the deposits are worked by open-pit or quarrying methods, often in a very crude way. Sand

deposits may be worked by hydraulicking, by dredging, or by the use of a steam shovel. Vein quartz is often obtained as a by-product in the mining of other materials. Pegmatite quartz is almost always obtained as by-product in working pegmatite dikes for feldspar or mica.

Little true flint is mined in this country either for grinding pebbles or for ground flint, and all flint marketed is imported, chiefly from Europe. Much of the material sold to the pottery trade as ground flint is either ground quartz, pulverized white tripoli, or ground sand, although considerable true flint is ground in this country, chiefly for ceramic purposes.

In the grinding and preparation of silica for market, several methods are used, depending upon the type of raw material, the character of the product desired, and the progressiveness of the producer. For ceramic use, silica is ordinarily ground to pass through a 140-mesh sieve, but for paint, polishes, fillers, etc., much finer grinding is necessary, a 325-mesh or even finer product being required. For sandpaper much coarser grains are needed, and these grains must be carefully graded by size.

Massive flint and crystalline quartz are very hard and tough. Crushing the crude rock is difficult and expensive, and to obviate this it may be calcined before crushing. Calcination has been done in a small vertical kiln resembling a lime kiln, fired with wood or coal, in which alternate layers of rock and fuel are placed. As the fuel burns away, the charge slowly sinks in the kiln, the heated rock being removed at the bottom and quenched with water. The calcined rock may then be broken down by hand and fed to "chaser mills" or crushed in jaw crushers, possibly followed by chaser mills. Fine grinding may be done either wet or dry. Wet grinding may be accomplished in conical mills, in short-tube mills, in long-tube mills, or in wet-grinding pans. If a wet-grinding process is used, the finished produce is usually sized by some system of water classification. Dry grinding may be done in conical mills, in short pebble mills of the intermittent type, or in long-tube mills. In dry-grinding methods, sizing of the finished product by air separation is common. The wet-ground product may be dried by steam in open tanks or over steam-pipe racks or in rotary driers.

The present tendency is to grind less flint and vein quartz and more glass sand, loosely consolidated sandstone, and tripoli, on account of the high cost of pulverizing the massive forms of silica.

Increasing demands for fillers and pigments of extremely fine particle size have led to efforts to grind silica down to the lower micron sizes by micronizing and by wet grinding in ball or pebble mills in closed circuit with a centrifuge. Because of the hardness of quartz these efforts have not been very successful. By chemical means, however, several companies have made, at least on a pilot-plant scale, pure silica pigments of a particle size close to that of carbon black, that is 0.01 to 0.05 μ . By one method ethyl silicate, a light-brown, volatile, and combustible liquid, is burned and the resultant fume or smoke of pure silica is collected. Suggested uses are as a filler in rubber and paint, as a catalyst carrier in chemical processes, and in the preparation of certain chemicals.¹⁶

Silica gel, made by reacting sodium silicate with an acid and drying and granu-

lating the resultant gelatinous silica, is an extremely porous, hard, adsorbent solid, used for many industrial processes of dehydration and adsorption.

Silicones are compounds of silicon and oxygen that contain hydrocarbon groups bound directly to silicon atoms. They are made from silicon tetrachloride (from silica sand and sodium chloride) plus organic chlorides and other organic compounds. Silicones cover a wide range in composition and physical properties—from liquids through semisolids to solids. Their usefulness depends in part upon their resistance to high temperatures, as in high-temperature varnish for electrical insulation and high-temperature-resistant greases.^{4,11,14}

Specifications and Tests. Very few standard specifications and tests exist for finely ground silica, but most products are sold on sample. For ceramic use, most consumers require a product 99 per cent of which will pass through a 140-mesh screen. They also require that the iron content be very low (sometimes less than 0.05 per cent). Amorphous silica in the form of ground flint or tripoli is often preferred by the pottery trade. For paint and for fillers, a 325-mesh product is usually required, although for some uses a still finer product is demanded. Angular grains are often preferred to rounded grains for use in paint and fillers. For abrasive purposes the grain size varies from a coarse, sharp sand (for coarse sandpaper) down to an impalpable dust (for fine polishes). It is important that abrasive silica have sharp angular grains rather than rounded grains.

Utilization. Table 6 shows the distribution of ground silica production by uses in the United States.

TABLE 6. GROUND SAND AND SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1946, BY USES*

Use	Short tons	Value	
		Total	Average per ton
Abrasive:			
Cleansing and scouring compound.....	103,247	\$ 626,158	\$6.06
Other.....	410	2,784	6.79
Enamel.....	24,723	167,537	6.78
Filler.....	26,204	204,531	7.81
Foundry.....	73,277	514,144	7.02
Glass.....	56,138	365,075	6.50
Pottery, porcelain, and tile.....	210,729	1,705,525	8.09
Other uses.....	26,328	197,085	7.49
Total reported by uses.....	521,056	\$3,782,839	\$7.26

* Data represent 90 per cent of the industry.

The principal uses for silica, together with the more common forms of silica now used for each, are shown in Table 7.

TABLE 7

<i>Uses of Silica</i>	<i>Types of Silica Used</i>
Abrasive uses:	
In scouring and polishing soaps and powders	Quartz, quartzite, flint, chert, sandstone, sand, tripoli, and diatomaceous earth; all in finely ground state
In sandpaper	Quartz, quartzite, flint, sandstone, and sand; coarsely ground and closely sized
In sand-blast work	Quartz, quartzite, sandstone and sand, crushed into sharp angular grains uniform in size
Metal buffing, burnishing, and polishing	Ground tripoli and other forms of ground silica
For sawing and polishing marble, granite, etc.	Sharp, clean sand graded into various sizes
As whetstones, grindstones, buhrstones, pulpstones, oilstones, etc.	Massive sandstone from very fine to moderately coarse grained
Tube-mill lining	Chert, flint, and quartzite in dense, solid blocks
Lithographers' graining sand	Medium to fine sand or rather coarsely ground silica and tripoli
Tube-mill grinding pebbles	Rounded flint pebbles
In tooth powders and pastes	Various forms of pure silica finely ground
Wood polishing and finishing	All forms of silica ground to medium fineness
Refractory uses:	
In making silica firebrick and other refractories	Fairly pure quartzite known as gannister; not less than 97 % SiO_2 nor more than 0.40 % alkalis, tightly interlocking grains desired
Metallurgical uses:	
In making silicon, ferrosilicon, and silicon alloys of other metals, such as copper	Moderately pure sand, massive crystalline quartz, sandstone, quartzite, or chert
As a flux smelting basic ores	Massive quartz and quartzite
Foundry-mold wash	Ground sandstone, quartz, and tripoli
Foundry parting sand	Fine sand and ground tripoli
Chemical industries:	
As a lining for acid towers	Massive quartz or quartzite
As a filtering medium	Massive diatomaceous earth and tripoli, sand, finely granular quartz or quartzite, finely ground tripoli, diatomaceous earth, and other forms of silica
In the manufacture of sodium silicate and other chemicals	Pure pulverized quartz sand, pure tripoli, and diatomaceous earth
In the manufacture of silicon carbide	Pure quartz sand
Paint:	
As an inert extender	Finely ground crystalline quartz, quartzite and flint, also finely ground sandstone, sand, and tripoli

TABLE 7. (Continued)

<i>Uses of Silica</i>	<i>Types of Silica Used</i>
Mineral fillers:	
As a wood filler	Finely ground crystalline quartz, quartzite, flint, tripoli, and other types of ground silica
In fertilizers	Finely ground silica of all types
In insecticides	
As a filler in rubber, hard rubber, pressed and molded goods, phonograph records, etc.	
In road asphalt surfacing mixtures	
Ceramic uses:	
In the pottery industry as an ingredient of bodies, glazes, and enamels	Flint, tripoli, and chert, and other amorphous silica preferred; also all other forms of very pure silica, all finely ground
In the manufacture of ordinary glass	Pure quartz sand
In the manufacture of fused-quartz chemical apparatus, such as tubes, crucibles, and dishes	Very pure massive quartz preferred
Decorative materials:	
In the manufacture of gems, crystal balls, table tops, vases, statues, etc.	Rock crystal, amethyst, rose quartz, citrine quartz, smoky quartz, chrysoprase, agate, chalcedony, opal, onyx, sardonyx, jasper, etc.
Insulation:	
Heat insulation for pipes, boilers, furnaces, kilns, etc.	Massive and ground diatomaceous earth
Sound insulation in walls, between floors, etc.	Massive and ground diatomaceous earth
Structural materials:	
Sand-lime brick	Moderately pure, sharp, angular sand, preferably finer than 20 mesh, together with a small percentage of finely pulverized silica
Optical quartz:	
For the manufacture of lenses and accessories for optical apparatus	Clear, colorless, flawless rock crystal
Fused quartz, clear	Clear, colorless, flawless crystal quartz
Fused quartz, translucent or opaque	High-grade glass sand
Oscillator plates	Clear, colorless, flawless, untwinned crystal quartz

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REFRACTORIES

Refractories are materials used to resist high heat. Their use in industry is essential to most high-temperature processes. They are of primary importance, therefore, to the metallurgical industries, the ceramic industries, the by-product coke industry, and the large number of operations concerned with the combustion of fuels. The general trend in many processes has been toward the employment of higher temperatures. This has been accelerated by the growing use of oxygen with fuels, the development of jet propulsion and rockets, the gas turbine, and the unusual problems associated with atomic energy. The demands for super-refractories therefore increase, and the possible use of temperatures thousands of degrees above those now employed has become the object of speculation in research.

Many materials are used for refractory purposes, each with its own characteristics and each particularly well adapted to certain specific uses. Some of these refractories are made from natural minerals, some from products directly derived from minerals, and some are made synthetically, usually in the electric furnace.

Materials Used for Refractories. In the following list are noted the most important refractory materials, nearly all of which are treated elsewhere in this book.

Natural Minerals and Derived Products

Andalusite	Olivine, forsterite
Bauxite	Pinite
Beryl	Sericite
Chromite	Silica, sand, and other forms
Diaspore	Sillimanite
Dolomite, dead-burned or specially treated	Soapstone
Fire clay	Spinel
Gannister	Talc
Graphite	Topaz
Kyanite	Tripoli
Magnesite, dead-burned	Zircon and zirkite
Mica schist	

Artificial (Electric-furnace Products)

Alumina (as alundum, etc.)
Graphite
Periclase

Silicon carbide (as carborundum, etc.)
Sillimanite
Spinel

Forms in Which Refractories Are Used. Although refractories are used in many forms and for many purposes, the most important form from the standpoint of quantity used is ordinary firebrick. In the following list are noted some of the principal forms in which refractories are used:

Assaying equipment, such as scorifiers
Cements
Chemical equipment
Condensers
Crucibles
Electrodes
Firebrick, standard and special shapes
Flues
Foundry facings

Glass-house refractories, pots, tank blocks, etc.
Grains, for example, dead-burned grain magnesite
Kiln muffles
Molds
Pyrometer tubes
Retorts
Saggers and other potters' equipment
Stove linings

Desirable Properties of Refractory Materials. An ideal refractory material has the following properties:

1. Has a very high melting point and a very high softening temperature
2. Is capable of being formed into the ordinary standard shapes
3. Is neutral in its chemical reaction, that is, not attacked by acid or basic slags, fumes, etc.
4. Exhibits little or no shrinkage or expansion upon heating to a high temperature
5. Has a high compressive and transverse strength both when cold and at high temperatures
6. Does not crack or spall upon sudden or slow heating or cooling
7. Is sufficiently hard and tough so that it is not easily worn away by abrasion or by the action of hot metal or slag
8. Is not unduly heavy
9. Is obtainable in quantity at moderate cost
10. Shows low slag penetration

There is no single refractory material in which all these desirable properties are combined. Fortunately, however, there are few uses for which all these properties are of prime importance, and for each use there are generally several refractories that are more or less suitable. As working temperatures increase, the choice of available refractories becomes narrowed, until at very high temperatures there are but few suitable refractories.

The field of refractories is an important one, and efforts are constantly being made to develop new and better refractories. The progress of very high-temperature electrometallurgy is dependent upon the development of refractories

that will withstand such temperatures. Some of the newer high-temperature refractories, sometimes called superrefractories, are those made from sillimanite, spinel, silicon carbide, alumina, zircon, zirkite (zirconium oxide), and periclase (electrically fused magnesium oxide).

Types of Refractories. *Silica Refractories.* Sandstone or quartzite, commonly called ganister, when used for refractory purposes is utilized in the manufacture of silica brick. In 1946, 1,034,270 short tons of such siliceous materials were used for refractory purposes. The best ganister should be a pure quartzite with over 97 per cent silica content. Alkalies and alumina should be low: alkalies not over 0.40 per cent and alumina below 1 per cent if such high-grade material can be obtained. The rock is crushed coarsely and ground for a short period with about 2 per cent by weight of hydrated lime. The bricks are pressed, dried, and fired to about 2625°F, which produces considerable conversion of the quartz to cristobalite and tridymite. These bricks are particularly useful in the roof of the basic open-hearth furnace and in by-product coke ovens.

*Fire Clay.*² Fire-clay refractories make up 50 per cent of the dollar value of the entire industry and about two-thirds of the volume. Clays of varying quality are found in many areas. Two-thirds of the production commonly originates in Ohio, Pennsylvania, and Missouri. A considerable tonnage of low-grade fire clay is used in Ohio in the manufacture of heavy clay products. The leadership of the state as a fire-clay producer is not reflected correspondingly in its importance as producer of refractories. In 1946, the total output of fire clay in the United States amounted to 7,907,974 tons. Fire clays are associated commonly with coal measures, and in some cases clay and coal have been produced at one operation. The properties of the finished refractory may be controlled by variations in composition, grinding, particle size, method of processing, and firing temperature. A considerable range of products may be secured, suitable for use in varying environments. Superduty fire-clay refractories are manufactured by the addition of approximately 10 per cent additional alumina. Their softening point is extended from 75 to 100°F.

High Alumina. High-alumina brick is more refractory than brick made from kaolin or fire clay. The higher the alumina content, the greater the refractoriness. Such brick is made with diaspore with a high-alumina content. The clays are blended with alumina to produce compositions with an alumina content varying from 50 to 80 per cent.

Magnesite and Chrome. Dead-burned magnesite is prepared from the mineral magnesite, and of late years from magnesium hydroxide recovered from sea water or other brines. Calcination is carried on at a temperature high enough to convert most of the magnesia to periclase. This appears in hard, inert nodules. Magnesite brick is molded from a dead-burned composition, with a magnesia content of around 85 per cent. They are fired at a high temperature to produce a strong brick. Periclase brick contains 90 per cent periclase and supplies a superior product with great refractoriness, high mechanical strength, and resistance to spalling.

Chrome brick is made from imported chrome ores averaging about 34 per cent chromic oxide. This is a lower grade ore than that employed for metallurgical

REFRACTORIES

uses, which will run from 48 to 50 per cent. The ore is crushed, ground, molded to brick, and fired at high temperature. The bricks are strong and constant in volume, and exhibit great resistance to chemical attack by slags. They are useful as a separating medium between materials that might react at furnace temperatures. They are used to separate magnesite brick from silica brick or fire clay. Blends of magnesite and chrome are being used for certain purposes, which is believed to be superior to the use of one constituent alone.

PRODUCTION AND SHIPMENTS OF REFRACTORIES IN THE UNITED STATES, BY KIND, in 1945* (Bureau of the Census)

Product	No. of plants	Unit of measure	Pro- duc- tion, quan- tity	Shipments	
				Quantity	Value, thou- sands of dollars
Clay and nonclay refractories, total.....	275				
Clay refractories, total.....	213				131,561
Fire-clay brick and standard shapes except superduty.....	118	1,000 9-in. equiv	514,040	532,254	67,775
Superduty fire-clay brick and standard shapes.....	27	1,000 9-in. equiv	64,719	68,651	32,732
High-alumina brick and shapes (50 % Al_2O_3 and over, except fused alumina).....	13	1,000 9-in. equiv	15,716	16,292	5,852
Insulating firebrick, standards, and special shapes.....	13	1,000 9-in. equiv	16,877	17,740	2,523
Ladle brick.....	21	1,000 9-in. equiv	156,184	157,723	1,948
Hot-top refractories.....	17	1,000 9-in. equiv	48,407	48,949	5,065
Sleeves, nozzles, runner brick, and tuyères.....	18	1,000 9-in. equiv	55,543	55,399	3,050
Glasshouse tank blocks, upper structure, and floaters.....	6	Short ton	21,359	21,593	3,825
Glasshouse pots (open and covered).....	4	Short ton	2,171	2,151	1,835
High-temperature bonding mortars.....	58	Short ton	63,067	62,036	291
Plastic refractories.....	47	Short ton	79,676	80,109	3,426
Cast and castables (hydraulic setting).....	33	Short ton	34,695	34,906	2,744
Other clay refractories, including kiln furni- ture and laboratory refractories (except porcelain).....	47	Short ton	77,063	77,739	1,566
Nonclay refractories, total.....	89				2,918
Silica brick and shapes.....	28	1,000 9-in. equiv	266,033	270,830	68,786
Magnesite and magnesite-chrome brick and shapes.....	4	1,000 9-in. equiv	16,691	16,642	18,476
Chrome and chrome-magnesite brick and shapes.....	4	1,000 9-in. equiv	30,537	30,384	6,405
Graphite and other carbon crucibles and retorts.....	8	Short ton	12,837	12,781	9,688
Other graphite and carbon refractories....	3	Short ton	1,218	1,291	5,288
Kiln furniture (saggers, posts and slabs, etc.)	7	Short ton	4,738	4,841	497
Laboratory refractories (muffles, crucibles, tubes, trays, etc.).....	4	Short ton	197	198	1,601
Other nonclay brick and shapes (of such material as silicon carbide, fused alumina, sillimanite, mullite, kyanite, forsterite, and zirconia).....	16				286
High-temperature bonding mortars.....	20	Short ton	26,018	26,052	7,091
Plastic refractories (including ramming mixtures).....	15	Short ton	89,088	88,930	1,431
Cast and castables (hydraulic setting).....	8	Short ton	4,888	4,855	4,358
Dead-burned dolomite†.....	17	Short ton		1,187,334	91
Nonclay refractory materials, sold in lump or ground form except dead-burned mag- nesia or magnesite.....	16	Short ton	66,840	66,325	10,614
Other nonclay refractories.....	11	Short ton	8,644	8,896	2,169

* Data revised. Data are excluded for dead-burned magnesia or magnesite to avoid duplication; a large part of such materials was shipped during 1945 to refractory-products manufacturing plants and was later incorporated in the refractory products covered in this report (such as magnesite brick and shapes). Data are also excluded for crude and prepared clays sold for refractory purposes.

† Represents dead-burned dolomite sold in 1945, as reported by the Bureau of Mines.

Special Refractories. An increasing number of mineral products are being used as refractories. Among them is forsterite derived from olivine. Forsterite has the composition $2\text{MgO}\cdot\text{SiO}_2$ with a melting point of 1910°C . Additions of magnesia must be made to the olivine to combine with serpentine or talc, commonly associated with olivine. Brick made from this composition is stable and competent to carry a heavy load at high temperatures. Zircon, the silicate of zirconium, is used in appreciable tonnage for the manufacture of brick and zirkite; the oxide is used in laboratory ware for special research. Mullite refractories, produced from a number of raw materials (see Aluminum Silicates), increase their usefulness in the glass industry and in the special porcelains in which they are employed.

Trends in Refractories. The trend toward the use of superrefractories and special compositions increases. The use of the more expensive product is justified by its longer life. The construction of a single blast furnace and its stoves in the steel industry will consume about 3 million bricks. The cost of installation is a major item. The greater life attained by the use of a superior product, therefore, may lower the refractory cost per ton of steel produced. The use of pure oxides as refractories is increasing. Magnesia and alumina, the most common and lowest priced, offer the most promise. Birch³ lists 18 elements whose oxides possess a melting point above 1800°C . Increasing interest is shown in the use of metal reinforcement in brick, the use of chemically bonded brick, actually burned in the furnace where they are used, in combinations of powdered metals and refractories, and in the carbides and nitrides of various elements.

Production and shipments of refractories in the United States are shown in the table on page 434.

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SALT (HALITE)

Composition. Salt is halite, or sodium chloride, NaCl: Na, 60.6 per cent; Cl, 39.4 per cent. Sometimes it is found very pure, but is commonly mixed with small quantities of calcium chloride, magnesium chloride, and calcium sulfate; less often with sodium sulfate, magnesium bromide or iodide, and magnesium sulfate. It is also often mixed with gypsum, anhydrite, organic matter, clay, and so on.

General Description. Salt is a soft, water-soluble mineral occurring as granular, crystalline or fibrous, often cleavable, masses, white, gray, brown, blue, or red in color. Crystals are cubical. It is easily determined by its characteristic taste.

Physical Properties. *Hardness*, 2 to 2.5. *Specific gravity*, 2.1 to 2.6. *Melting point*, 801°C. *Index of refraction*, 1.544. *Color*, white, colorless, yellow, brown, gray, blue, or reddish. *Streak*, white. *Luster*, vitreous. *Cleavage*, excellent cubical. *Fracture*, conchoidal. *Transparency*, transparent to translucent. *Tenacity*, brittle. *Taste*, characteristically salty. Easily soluble in cold water (1 part in 2.8 parts of water).

Occurrence. Salt, one of the commonest and most widely distributed minerals, has four distinct modes of occurrence: (1) extensive deposits of rock salt; (2) salt solutions; (3) as sublimation products near volcanoes; and (4) as efflorescent, earthy crusts in arid regions. Of these types only the first two are of commercial importance.

Salt deposits occur in sedimentary rocks of nearly all geologic ages since the

early Cambrian, and salt deposition is going on at present. It often occurs in very extensive deposits either as single beds of salt or interbedded with gypsum, anhydrite, clay, dolomite, and so on. Single beds of salt several hundred feet thick are common, for example, in Louisiana, where a thickness of over 2,700 ft is reported at one point. The great Permian salt deposit of the south-central United States is estimated to have an area of about 100,000 square miles and an average thickness of at least 200 ft. Several theories have been advanced to explain the origin of such very large salt deposits, but the so-called "bar theory" of Ochsnius is most generally accepted. This theory, which has been summarized by Phalen,¹⁷ presupposes an inland lake or shallow lagoon of sea water, separated from the ocean by a bar of such a height and width that only so much sea water could flow into the lake as could be evaporated from its surface. Thus the salinity of the lake would gradually increase until the saturation point would be reached and the salts would crystallize out, building up a bed of salts on the lake bottom until something interrupted the process.

Saline solutions include the oceans, salt seas and lakes, and saline springs and wells. Such solutions, together with artificial brines, form the largest present commercial sources of salt.

Geographically, salt deposits or sources of saline solutions are common in practically every country of the world and only the more noted localities will be mentioned here.

For many years the United States has been the largest salt-producing country of the world, with China, Russia, Germany, and Great Britain close contenders for second place. France and India are very large producers, with Italy, Spain, Austria, Canada, Brazil, and Argentina following more or less in order of importance and with dozens of smaller producing countries.

*United States.*¹⁷ For many years Michigan has usually been the largest domestic producer, with New York second and Ohio a close third. Other states with 5 per cent or more of the total production in recent years have been Louisiana, Texas, Kansas, and California. Other producing states are West Virginia, Utah, Virginia, Nevada, Oklahoma, and New Mexico.

Michigan. The salt produced in Michigan is obtained from (1) rock salt and (2) natural brines. The rock-salt industry is of much greater importance than the natural-brine industry.

The rock-salt areas are (1) in the southeastern part of the state along the Detroit and St. Clair rivers; (2) along the western shore of the Lower Peninsula (Manistee and Mason counties); (3) near Alpena on Thunder Bay (undeveloped). The rock-salt beds are in the Salina formation, underlying the Munroe group (Silurian), occurring at usual depths of 1,600 to 1,700 ft. The rock-salt deposits are worked both as mines and as sources of artificial brines.

Natural brines, produced only in Saginaw Valley, occur in the Marshall sandstone of the Mississippian series, chiefly near Bay City, Saginaw, Midland, Mount Pleasant, and St. Charles. These brines yield not only salt, but also bromine and calcium and magnesium chlorides.

New York salt production all comes from deposits of rock salt that are either mined as such or used as sources of artificial brines. The salt field of New York

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is confined to the area underlain by the salt-bearing Salina formation. This outcrops as a belt 12 miles wide at Niagara River, extends eastward across parts of Genesee, Monroe, Wayne, Ontario, Seneca, Cayuga, and Onondaga counties to a point just south of Oneida Lake. There it turns slightly southward, gradually getting narrower, until it terminates at Schoharie. Its greatest width, about 20 miles, is at the foot of Cayuga and Seneca lakes. This series of beds dips gently to the south and, as the salt has been leached from the outcrop, salt production all comes from the south side of the outcrop. The principal producing counties are Wyoming, Livingston, Genesee, Onondaga, Tompkins, and Schuyler. Rock salt is mined at a few places in Livingston County (as at Retsof), but most of the salt produced is from artificial brines, made by allowing water to come in contact with the rock salt in place.

Ohio. No rock salt is produced in Ohio by mining, but the entire production is derived from either natural or artificial brines. There are two producing districts, one in northeastern Ohio and one in the southeastern part of the state.

The northeastern area, consisting of beds of rock salt, is large, but production has been restricted to Cuyahoga, Summit, Medina, Lake, and Wayne counties. Part of the artificial brines produced is not used as sources of salt, but other sodium compounds are made directly from it.

The southeastern area centers about Pomeroy, Meigs County, where natural brines, in sands and sandstones, are worked for bromine, calcium chloride, and common salt.

Kansas is a large producer of salt, both mined rock salt and evaporated salt made from artificial brines. The salt deposits of Kansas are a northerly extension of the great Permian salt deposits that are known to underlie parts of Kansas, Oklahoma, Texas, and New Mexico and may extend into the southeast corner of Colorado and into southern Nebraska. The limits of this deposit are not fully known, but, in general, the area of thick salt beds extends fully 650 miles north and south and 150 to 250 miles east and west. The thickness is very variable, but 200 ft is reported at one locality and in many places the aggregate is more than 300 ft.

It has been estimated that the total area is about 100,000 square miles, which, with an assumed average thickness of 200 ft, represents a gross quantity of about 30,000 billion tons. This is the largest known salt deposit in the world.⁸

Most of the deposits now being worked are in central and south-central Kansas. Rock salt is mined at Lyons and Kanopolis, and salt is produced from artificial brines at Ellsworth, Hutchinson, Sterling, Lyons, Anthony, and elsewhere.

Louisiana. All the salt produced in Louisiana is mined as rock salt. Salt deposits occur in the north and north-central parts of the state, but the most important deposits, and those now worked, are in the southern part close to the Gulf of Mexico. The most important deposits of the southern area are on the Five Islands or Salt Islands, namely Petite Anse (Averys Island), Grande Côte (Weeks Island), Belle Isle, Côte Blanche, and Côte Carline (Jefferson Island). Rock salt is now being mined on an extensive scale on the first two of these islands, and on Jefferson Island.

All these deposits are domes of the typical salt-gypsum-sulfur dome structure

of the Gulf section of Texas and Louisiana. In the tops of the domes the salt comes to within 100 to 400 ft of the surface and is overlain by clay, sand, and gravel; but on the flanks of the domes the overburden is much greater. The Myles Salt Co. deposit is over $1\frac{1}{2}$ miles in diameter and of an unknown depth. Several drill holes put down in these deposits have shown a thickness of from 2,000 to over 2,700 ft. The salt in these deposits is very pure.

California. All forms of salt occurrences are found in California, but more than 97 per cent of the salt produced in the state is made by the solar evaporation of sea water along the coast. This industry centers about San Francisco Bay in Alameda and San Mateo counties; near Long Beach, Los Angeles County; and on San Diego Bay, San Diego County.

Owens Lake and Searles Lake and other smaller alkaline lakes and lake beds in Inyo and San Bernardino counties contain very large quantities of salines, both solids and brines, of which common salt usually forms a large proportion. These salines also contain other salts of sodium, such as carbonates, sulfates and borates, as well as potassium salts. The deposits have been worked to a very small extent for common salt, but have been of principal interest as sources of potash (see Potash Salts).

Texas. Most of the salt produced in Texas in recent years has come from Palestine, Anderson County, and Grand Saline, Van Zandt County, in the eastern part of the state. These deposits, which are rather shallow and localized, resemble those of Louisiana but do not form domes. The salt is recovered by the evaporation of artificially made brines. Salt occurs in large quantities in the Gulf Coast domes of southeastern Texas.

Utah. The greater part of the salt produced in Utah is made by the solar evaporation of the waters of Great Salt Lake, principally at Saltair, about 15 miles west of Salt Lake City, but also on a much smaller scale at several other points. Rock salt occurs in Sevier Valley near Salina, Redmond, and Gunnison.

Virginia. Salt deposits of commercial importance occur in but one district in Virginia. This deposit, which also contains gypsum, underlies for about 20 miles the valley of the north fork of the Holston River, in Smyth and Washington counties. Practically no salt is produced as such, but brine is pumped from drilled wells and converted into other sodium salts at Saltville.

Other States. Although salt is produced in several other states and many other extensive, but little worked, deposits are known, they are not of sufficient present commercial importance to warrant description.

Production. *World Production.* Statistics of salt production are reported by over 80 countries and several others are known to be salt producers. Table 1 shows production in some of the more important producing countries in recent years.

United States Production and Consumption. Salient statistics of the production and consumption of salt in the United States for recent years are given in Tables 2 to 4.

In 1946 the United States production of rock salt came from 19 plants in 8 states; that of evaporated salt came from 49 plants in 12 states and Puerto Rico. Brine salt, used for the production of chemicals or in chemical processes without

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being concentrated into the solid state, was produced in 1946 in 15 plants in 7 states.

Mining and Milling.^{6,7,12,13,16,20,24,25} The methods of salt production vary widely in different parts of the world, depending not only upon the source of the salt (rock salt or brines), but also upon the nature and the cost of the fuel available, climate, costs of labor, quality of product desired, size of output, and so on. Salt has been manufactured since the dawn of history, and early processes were

TABLE 1. WORLD SALT PRODUCTION IN RECENT YEARS, METRIC TONS

Area	Metric tons	Year
United States.....	13,727,579	1946
China.....	5,197,914	1942*
Russia.....	over 4,500,000	†
Germany.....	4,020,000	1944*
Great Britain.....	3,285,135	1946
India.....	2,231,154	1945
France.....	2,134,350	1939*
Italy.....	1,476,644	1941*
Spain.....	772,772	1946
Japan.....	636,382	1939*
Canada.....	481,032	1946
Brazil.....	453,601	1944*
Argentina.....	400,000	1946†
Korea.....	350,000	1943*,†
Poland.....	271,000	1939*,†
Austria.....	262,719	1939*
Egypt.....	226,090	1946
Turkey.....	225,917	1946
Total world production.....	35,545,000	1946†

* For various reasons, such as disruptions in normal production due to war or non-availability of statistics, more recent production statistics, even where available, are not considered typical of productive capacity.

† Estimate.

not greatly improved upon until the beginning of the nineteenth century. Improvement then was gradual until the development of modern methods of steam evaporation in the "grainer" process and the vacuum-pan process. The introduction of these methods greatly increased both production and efficiency. A general outline of the various methods of salt recovery, as given by Cole,⁷ is shown in Fig. 11.

The distribution of United States production by methods of recovery is shown in Table 4.

Rock Salt. Rock salt is recovered by mining or quarrying and by solution in water with subsequent evaporation of the resulting artificial brine, or with direct use of such brines for the manufacture of chemicals. In the United States nearly 23 per cent of the production is now mined rock salt.

TABLE 2. SALIENT STATISTICS OF THE SALT INDUSTRY IN THE UNITED STATES, 1935 TO 1939 (AVERAGE) AND 1942 TO 1946

	1935-1939 (average)	1942	1943	1944	1945	1946
Solid or used by producers:						
Evaporated (manufactured), short tons.....	2,507,374	3,517,832	3,476,501 ^a	3,448,578 ^a	3,182,570 ^a	3,249,457
In brine, short tons.....	4,205,587	7,373,165	8,478,513 ^a	8,820,355 ^a	8,705,831 ^a	8,470,680
Rock salt, short tons.....	1,947,254	2,802,287	3,259,138	3,448,238	3,505,740	3,412,008
Total, short tons.....	8,660,215	13,693,284	15,214,152	15,717,171	15,394,141	15,132,145
Total, value ^b	\$23,405,672	\$38,144,234	\$41,529,688	\$43,715,492 ^a	\$43,914,406 ^a	\$44,912,586
Average per ton ^b	\$2.70	\$2.79	\$2.73 ^a	\$2.78 ^a	\$2.85 ^a	\$2.97
Imports for consumption:						
For curing fish, short tons.....	21,250 ^c	6,443 ^c	.....	.....	.....	1,407
Value.....	\$43,722 ^c	\$17,667 ^c	.....	.....	.....	\$5,011
In bags, barrels, etc., short tons.....	1,385	367	129	14	1,572	275
Value.....	\$11,813	\$4,138	\$2,425	\$700	\$36,343	\$4,456
In bulk, short tons.....	24,131	953	1,129	5,540	2,981	2,571
Value.....	\$55,876	\$7,496	\$10,325	\$31,459	\$37,047	\$20,161
Total, short tons.....	46,766	7,754	1,258	5,554	4,553	4,253
Total, value.....	\$111,411	\$29,301	\$12,750	\$32,159	\$73,390	\$29,628
Exports:						
Short tons.....	90,214	118,424	145,803	198,368	190,524	223,426
Value.....	\$521,652	\$892,160	\$1,173,139	\$1,620,226	\$1,509,301	\$1,889,522
Apparent consumption, ^d short tons.....	8,616,767	13,582,614	15,069,607	15,524,357	15,208,170	14,912,972

^a Revised.^b Values are fob mine or refinery and do not include cost of cooerage or containers.^c Includes salt in bags, sacks, barrels, or other packages—1938: 93 tons, \$673; 1942: 122 tons, \$1,200.^d Quantity sold or used by producers plus imports minus exports.

TABLE 3. SALT SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY STATES

State	1944			1945			1946		
	Quantity		Value	Quantity		Value	Quantity		Value
	Short tons	Per cent of total		Short tons	Per cent of total		Short tons	Per cent of total	
California.....	712,558	5	\$3,138,185	694,609	4	\$3,424,711	729,092	5	\$3,358,060
Kansas.....	932,238	6	4,357,217	855,806	6	3,837,850	815,018	5	4,014,919
Louisiana.....	1,843,728	12	4,102,020	1,867,689	12	4,465,643	1,846,522	12	4,612,359
Michigan.....	4,287,758	27	14,921,719	4,285,493	28	14,942,443	4,334,202	29	15,711,074
New Mexico.....	23,759	*	105,860	9,980	*	20,694	8,677	*	16,399
New York.....	2,925,675	19	9,899,580	2,862,224	19	10,327,013	2,813,782	19	10,153,274
Ohio.....	2,891,395	18	4,076,481	2,764,926	18	3,997,759	2,645,995	17	4,160,011
Puerto Rico.....	13,620	*	87,114	12,513	*	81,200	12,411	*	83,494
Texas.....	1,147,397	7	1,353,756†	1,100,791	7	1,336,162†	1,098,589	7	1,356,676
Utah.....	119,809	1	368,500	122,997	1	363,997	121,669	1	339,505
West Virginia.....	359,217	2	1,027,109	370,260	2	903,759	272,841	2	896,894
Other states†.....	460,017	3	277,951	446,853	3	213,175	433,347	3	209,921
	15,717,171	100	\$43,715,492	15,394,141	100	\$43,914,406†	15,132,145	100	\$44,912,586

* Less than 0.5 per cent.

† Revised.

‡ Includes Nevada, Oklahoma, and Virginia.

TABLE 4. SALT SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY METHOD OF RECOVERY

Method of recovery	1945*		1946	
	Short tons	Value	Short tons	Value
Evaporated:				
Bulk:				
Open pans or grainers.....	637,529	\$ 5,961,143	558,026	\$ 5,905,704
Vacuum pans.....	1,846,011	14,144,622	1,840,061	14,165,778
Solar.....	446,112	1,712,171	553,056	1,971,947
Pressed blocks.....	252,918	2,553,161	298,314	2,942,966
Rock:				
Bulk.....	3,410,929	12,115,237	3,314,948	12,479,589
Pressed blocks.....	94,811	849,154	97,060	828,412
Salt in brine (sold or used as such)	8,705,831	6,578,918	8,470,680	6,618,190
Total.....	15,394,141	\$43,914,406	15,132,145	\$44,912,586

* All data revised except quantity and value of rock salt and total quantity (but not value) sold or used.

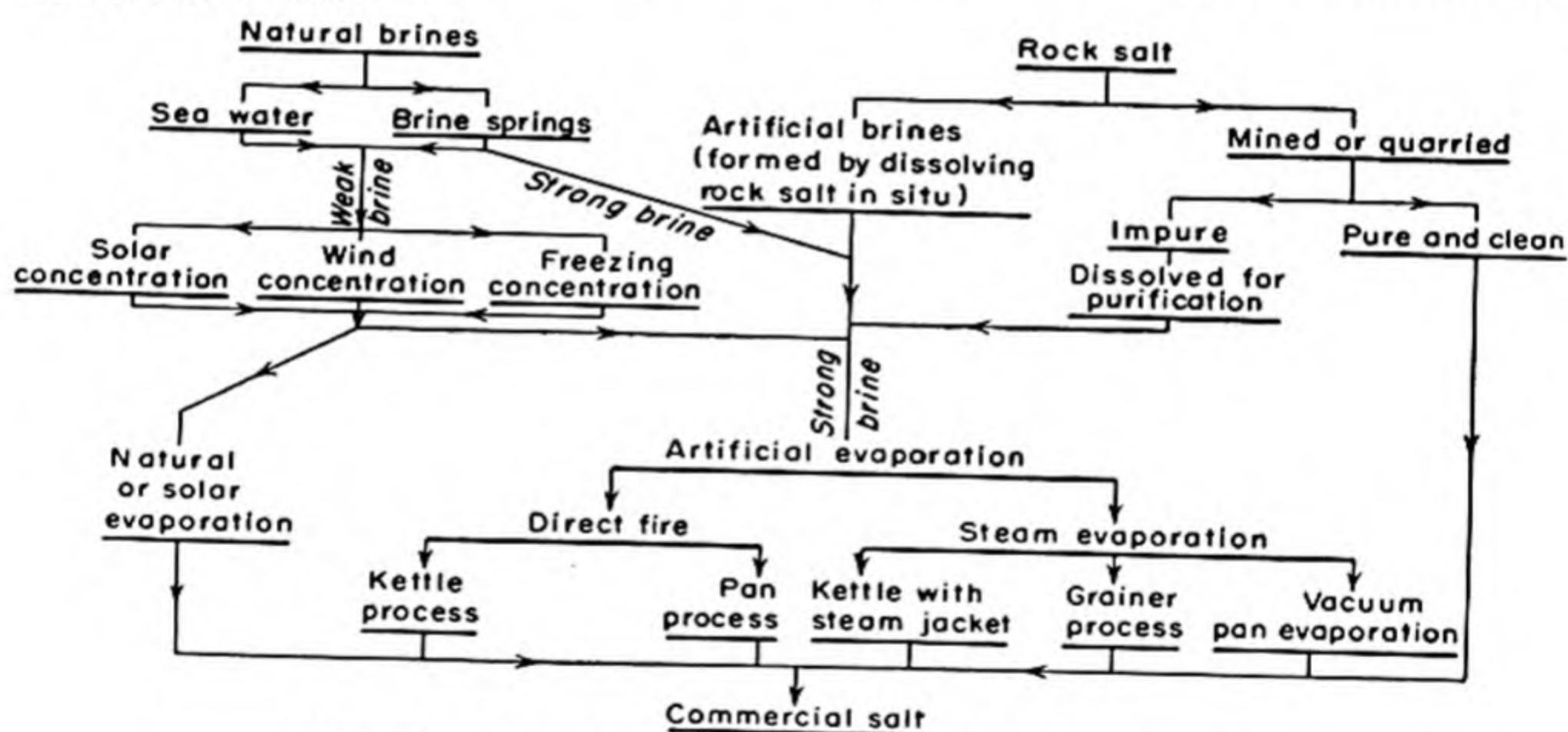


FIG. 11. Flow sheet showing method of salt recovery.

Rock-salt Mining and Milling. Rock salt is mined in the United States chiefly in New York (at Retsof and Halite), in Michigan (near Detroit), in Kansas (Kanopolis, Hutchinson, Lyons, and Kingman), in Louisiana (Weeks, Averys, and Jefferson Islands), in Texas (near Hockley), and in Utah (Axtell and Redmond).

The mines are usually opened by vertical shafts varying in depth from 500 to about 1,200 ft. In most of the mines salt is first encountered at a depth greater than 500 ft, but in Louisiana, in the tops of the domes, salt is reached within 40 to 60 ft of the surface, although the working shafts are 500 to 750 ft deep.

The mines are systematically developed by a room-and-pillar system. The salt is drilled by compressed air or electric augers, shot down with low-strength dynamite, loaded into cars, and hoisted to the surface. The lump salt is then milled by alternate crushing (usually in toothed or corrugated rolls) and screening to the desired sizes (in revolving, or inclined impact or vibrating screens) and is then packed for shipment.

In some cases the rock salt as mined is not pure enough to be marketed. In such cases it is dissolved in water and evaporated by one of the methods described later. If the chief impurity is glauber salt (sodium sulfate) it may be purified by heating in a kiln to 300°F, at which temperature the sodium sulfate is dehydrated and blown out by the air current in the drier.³

Artificial Brines. Where the rock-salt beds are too far below the surface to permit economical mining, or where the salt contains impurities that must be removed by recrystallization, the common practice is to drill holes down to the salt beds, dissolve the salt with water and pump the brines to the surface. Drill holes, usually 8 to 10 in. in diameter at the collar, are put down by means of churn drills. Usually the holes are continued several feet through the salt bed and then sprung or blasted to form a collecting chamber for the brine. The holes are then cased to prevent leakage of brine. These drill holes are usually several hundred feet deep—in places as much as 2,300 ft.

Water from any convenient source is introduced into the well. There are several methods of raising the resultant brine, of which the following are the more common:

1. By pumping with an ordinary air-lift pump. Compressed air is introduced at the bottom of the well through a pipe down the center of the casing, which is filled with brine. The air, rising in bubbles, raises the brine to the surface and then escapes as the brine leaves the pipes to enter the first settling tanks.

2. By the hydraulic method. In this method pure water, under great pressure, is forced down to the bottom of the well through the annular space about an inner pipe. The brine formed is forced up to the surface through the inner pipe. Sometimes, when two or more wells are connected underground, the water is pumped down one well and the brine rises in another well.

3. By means of a plunger pump or "sucker rod" and walking beam, of the cornish-pump type. This method is now largely superseded by one of the other methods noted above.

The artificial brines are either used directly in the manufacture of other sodium salts or evaporated by one of the methods later described.

Natural Brines. Natural brines may be divided into three classes: (1) sea water, (2) salt lakes, and (3) brine springs.

Sea water, from the earliest times, has been one of the commonest sources of salt. Since the discovery of large deposits of rock salt and the development of efficient methods of artificial evaporation, this source has declined in importance, but it is still used where climatic conditions are favorable. For example, nearly all the salt produced in California is made by the solar evaporation of sea water, and the solar sea-salt industries of Spain and Italy still flourish.

Salt lakes and inland seas, such as Great Salt Lake in Utah, Owens and Searles lakes in California, the Dead Sea of Palestine, and so on, are still important sources of salt made by solar evaporation.

Brine springs have been important sources of salt in many countries in the past, but at present they are of little importance.

Solar Evaporation of Brines. In Ponds. Natural evaporation, using wind and the heat of the sun, is used chiefly for the recovery of salt from sea water and salt lakes, but it may also be used to recover salt from rather weak brine springs or even from artificial brines. Martin¹⁴ gives the composition of sea water shown in Table 5.

TABLE 5. COMPOSITION OF SEA WATER
(No. of grams in 100 g of sea water)

	Ocean	Mediterranean	Dead Sea
NaCl.....	2.723	3.007	8.79
MgCl ₂	0.334	0.385	8.99
MgSO ₄	0.225	0.249	
CaSO ₄	0.126	0.140	0.14
KCl.....	0.077	0.086	1.36
MgBr ₂	0.008	0.008	0.37
CaCO ₃	0.012	0.012	2.38
Total salts.....	3.505	3.887	22.03

To every 100 g of sodium chloride (NaCl) in ocean salt there are:

	Grams
NaCl.....	100.00
MgCl ₂	12.27
MgSO ₄	8.26
CaSO ₄	4.62
KCl.....	2.83
MgBr ₂	0.29
CaCO ₃	0.44

The salinity of the waters of Great Salt Lake, Utah, varies from about 14 to about 28 per cent; thus the concentration is from four to seven times that of sea water. The magnesium and calcium salts are also proportionately lower than in sea water.

Solar evaporation is carried on in shallow ponds or in shallow wooden vats, called "rooms." The latter method is not now in common use.

Salt ponds or "salt gardens" or "salt meadows" are large shallow ponds, divided into several sections by low walls or embankments, located well above high-water level. At individual plants the total area of ponds may vary from less than 500 acres in small plants to over 2,000 acres in large plants. The dividing dikes may be as high as 3 ft, and 1 or 2 ft above the brine level. The individual ponds may be so arranged that the brine may flow by gravity from the intake

pond to each succeeding pond; or the brine may be pumped from one to another. The crude brine is pumped from the ocean or lake into the intake ponds.

At the beginning of the salt-making season, the brine (of an average density in sea water of 3.5°Bé) is pumped into the intake ponds, where it is allowed to evaporate for a variable length of time. The partly concentrated brine is then passed on to succeeding ponds, where the concentration is gradually increased until the density reaches about 25°Bé , or nearly the saturation point. Crude brine is again admitted to the intake ponds and the process continues. The saturated brine is then run into the crystallizing ponds to a depth of about 6 in., where it evaporates to a density of from 27 to 29°Bé . Here the salt crystallizes out. The mother liquor is then run into other ponds, where crystallization continues and the concentration rises to about 32°Bé . In these ponds salt of an inferior quality is obtained. The residual bittern, carrying calcium, magnesium, and potash salts, may be allowed to go to waste, or it may be used as a source of these other salts.

Mechanically held impurities, such as clay, in the crude brine usually settle out in the intake or settling ponds. In the first few ponds the calcium carbonate and gypsum (CaSO_4) also separate out.

The crystallized salt is raked into heaps and allowed to drain. It is then shoveled into small cars and trammed to the storage yards, where it is stacked. In more modern and efficient operations the salt may be harvested mechanically. The salt yield per season varies with the climate. In the San Francisco Bay district the yield per season averages 5 or 6 in. of salt, but at San Diego two 6-in. crops may be made each season.

The salt, as harvested, contains adhering bittern and dirt and must be washed before milling. It is usually washed in saturated brine, either concentrated sea water or pure salt brine. It is then crushed, rewashed, drained, and either allowed to dry as coarse salt or dried in various forms of centrifugal machines and driers. The dried salt is recrushed and screened into the market sizes.

Wind Concentration or Graduation Method. In some parts of Europe, chiefly in France and Germany, weak brines from brine springs have sometimes been partly concentrated by allowing them to trickle slowly over walls of thorns or brushwood exposed to the sun and wind. This process is called "graduation" and is carried on in "graduation houses." The distribution of the brine over the brushwood exposes a very large area to the evaporating action of the wind. The concentrated solutions are of sufficient strength to be treated by one of the methods of artificial evaporation.

Concentration by Freezing. When a salt brine is cooled to the freezing point of water, pure water will freeze out, forming ice and leaving the salt in solution until a definite concentration of the residual salt brine is reached. Then the residual brine will also freeze. If a weak brine, such as sea water, is subjected to a freezing temperature, and the nearly pure ice removed as fast as it is formed, a concentrated brine can be obtained, containing about 23.6 per cent sodium chloride (theoretically). This brine may then be evaporated by one of the methods of artificial evaporation. In cold climates, such as in northern Europe, this method of concentration has been used to some extent.

Evaporation of Brines by Artificial Heat. The methods of recovery of salt by evaporation using artificial heat may be classified as follows:

1. Direct-heat evaporation
 - a. In open kettles
 - b. In open pans
2. Steam evaporation
 - a. In jacketed kettles
 - b. In grainers
 - c. In vacuum pans

The brines evaporated by these processes may be either natural or artificial, but, in order that the recovery may be economical, the solutions must be fairly concentrated.

In the *open-kettle process*, as ultimately developed, iron kettles about 2 ft deep by 4 ft in diameter were set, in groups or "blocks" of 30 to 100 kettles each, in parallel lines within flues or arches terminating in chimneys. At the end of the block opposite the chimney end was a grate or firebox in which a wood fire was maintained. The brine, from which the iron had been previously precipitated by milk of lime, was placed in the kettles and allowed to boil. During evaporation the sediment, which collected before saturation, was removed several times. The salt was removed by hand and drained. This method has been gradually abandoned.

In the *open-pan process* the brine is first settled; then milk of lime is added and the solution is stirred mechanically or by hand to remove iron compounds. In some cases soda ash is also added to remove any excess of lime. The solution is then allowed to stand for some time until perfectly clear. Next it is run into the evaporating pans, either with or without preheating.

The pans used are usually made of riveted, wrought-iron plates, 12 to 18 in. deep, 100 to 115 ft long, and 23 to 30 ft wide, with flaring sides. They may be divided into front pans and back, or preheating, pans. A firebox is located at one end and a flue or stack at the other. The fuel may be coal, crude oil, or natural gas. A typical pan is illustrated by Phalen.¹⁶

The brine is first run into the back pan, where it is preheated, and then siphoned into the front pan. When sufficient salt has crystallized out, it is removed to the drainboards, usually by hand rakes, and there allowed to drain. The front pan is refilled from the back pan, the latter refilled with brine, and the process continued.

This process is now less extensively used than the grainer and vacuum-pan processes.

Evaporation in *steam-jacketed kettles* resembles the process of open-kettle evaporation, but the kettles in the blocks are heated by steam jackets instead of by direct heat. This process is now practically superseded by the grainer and vacuum-pan processes.

The *grainer process* is distinctly an American process, having been developed in Michigan, where salt making for many years was merely an adjunct to the lumber

business. The method was designed primarily to utilize waste lumber and waste steam, and in some places salt making is still a minor phase of some other industry.

The grainers used in different districts vary considerably in detail, but in essential principles they are very similar. In general, they consist of wood, metal, or concrete vats 100 to 160 ft long, 10 to 24 ft wide, and 18 to 24 in. deep. Coils of galvanized iron pipes, $2\frac{1}{2}$ to 5 in. in diameter, are suspended in these vats, possibly a foot or less above the bottoms of the vats. Through the coils live or exhaust steam or "tail water" (waste hot water) circulates. The salt is removed either by hand rakes or by some form of continuous or intermittent mechanical rakes or scraper conveyors. Sometimes the grainer is of V-shaped section in order to facilitate the removal of salt by a continuous-scraper conveyor.

The crude brines are first settled and purified, as described above under the open-pan process, and then are usually run into preheating tanks. These tanks, in a general way, resemble grainers, but are usually 6 to 8 ft deep and have no rakes. The preheated brine is run slowly but continuously into the grainers, where the solutions slowly evaporate; salt crystallizes out and is continuously removed to drainboards. The process must be interrupted and the bitters removed once in 24 to 72 hr, depending on the quality of the salt being made. These bitters may be wasted or used as sources of magnesium chloride and bromine. Sometimes they are first reworked in other grainers to obtain lower grades of salt.

The speed of crystallization, and therefore the grain size and purity of product, may be easily regulated in this process.

The *vacuum-pan process*^{6,16} is based on the principle that when the pressure on the surface of a liquid is decreased the boiling point is correspondingly decreased. This process thus results in greater fuel efficiency and is used in nearly all the most modern and efficient salt plants in the United States. Heat is always furnished by live or exhaust steam.

Vacuum pans are large, conical-shaped metal tanks that consist of four essential elements, namely, the evaporating and condensing chambers, the heating element (steam chamber or coil), the coned bottom (in which the salt collects), and the salt filter or barometric leg (by means of which the crystallized salt may be removed without interrupting the process). Several such pans are used in series (double, triple, or quadruple effects).

Salt made by the vacuum-pan process is mostly of very fine grain, and the grain size cannot be so easily regulated as in the grainer process.

The sketch (Fig. 12) by Phalen¹⁶ shows the essential parts of a vacuum pan.

Vacuum pans vary considerably in size. The most common range in diameter is from 10 to 20 ft, but 30-ft pans have been made. Pans 10 to 20 ft in diameter usually measure 30 to 50 ft vertically from tip to tip of the end cones and therefore have to be tended from different floors.

Preparation of Salt for the Market.⁶ All salt, whether manufactured in the vacuum or open pan, is generally allowed to age or season for at least 2 weeks before being shipped, either in bulk or in barrels. This seasoning gives time for the salt to become thoroughly drained and free from excess brine.

For table and dairy salt, a further treatment is carried on before the salt is

placed on the market. The crude salt is passed through long, cylindrical, rotating driers, in which a current of hot air is blown through in the opposite direction to that in which the salt is moving, *i.e.*, in a direction opposite to the inclination of the drier. After being thoroughly dried, it is passed through a series of screens of various sizes, and is then automatically bagged and sold as dairy, table, and cheese salt. Each company has a special trade name under which it markets its product.

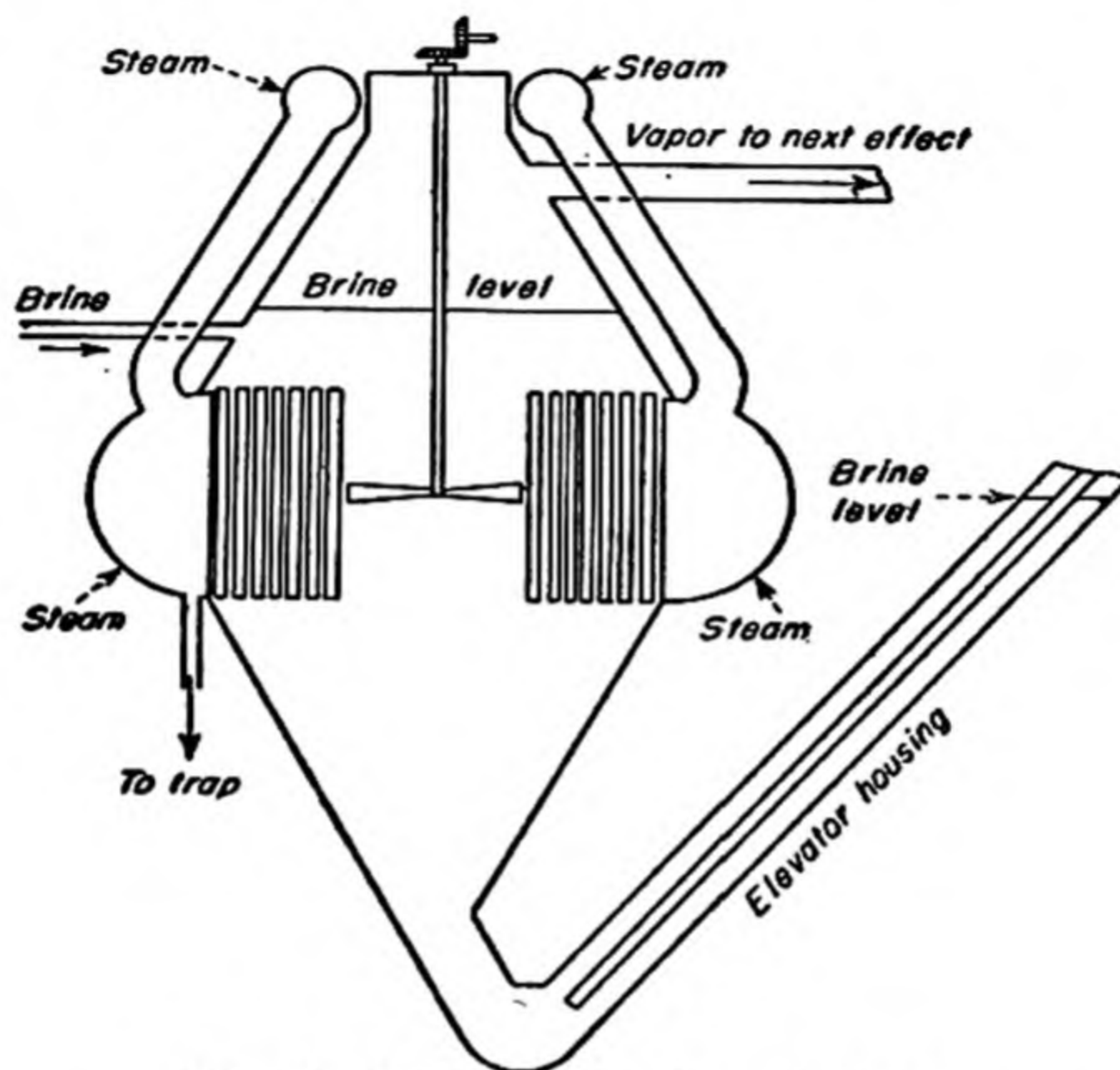


FIG. 12. Essential parts of vacuum pan.

Frequently, small amounts of other chemicals are added to the salt to impart special properties. In order to make table salt free-running, small amounts (usually less than 1 per cent) of some nonhygroscopic salt, such as magnesium or calcium carbonates or phosphates, are added to coat the salt grains. In areas where goiter is prevalent, as in the Great Lakes region, iodized salt is made by adding very small quantities of potassium iodide. To pressed salt blocks used for salting cattle sulfur may be added.

Recovery of By-products.* Sea water and most other natural and artificial brines, in addition to NaCl, contain in varying proportions, some or all of the

* For descriptions of methods of recovery of bromine, calcium chloride, and so on, see W. C. Phalen, *Technology of Salt Making in the United States*, U.S. Bur. Mines, Bull. 146, 1917, pp. 80-97; also general inorganic industrial chemistries, such as Geoffrey Martin, "Industrial and Manufacturing Chemistry," Pt. 2, Inorganic, Vol. 1, p. 262, Edward Lockwood & Son, London, 1917; Allen Rogers "Industrial Chemistry," D. Van Nostrand Company, Inc., New York; and Edward Thorpe, "Dictionary of Applied Chemistry," Longmans, Green & Co., London.

SALT (HALITE)

following salts: MgCl_2 , MgSO_4 , CaSO_4 , CaCl_2 , KCl , MgBr_2 , and CaCO_3 . After the removal of the sodium chloride by evaporation and crystallization, the resulting bitterns are concentrated solutions of these other salts. Often they are wasted, but in recent years they have been used to an increasing extent as sources of calcium chloride, bromine, magnesium chloride, epsom salts ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), glauber salts ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), and potash salts. In the United States the chief products that have been recovered have been calcium chloride, bromine, iodine, and magnesium salts.

Bromine recovery is discussed under Bromine. *Magnesium salts* recovery is covered under Magnesite and Magnesium Salts.

Calcium chloride, recovered from natural brines, in recent years has ranged from 200,000 to over 262,000 tons per year in the United States, with an average value of a little over \$8 per ton at producing plants. It competes with a much larger tonnage of by-product calcium chloride produced in the ammonia-soda process. In 1946, 10 plants in California, Michigan, and West Virginia produced calcium chloride and calcium-magnesium chloride from natural bitterns.

Marketing, Shipping, and Prices. Salt is marketed or used chiefly in the following forms: (1) table salt, (2) dairy salt, (3) packers' salt (common fine and common coarse), (4) coarse solar salt, (5) pressed blocks and coarse lumps (for salting cattle), and (6) as brine (used for manufacture of other sodium salts, chlorine, hydrochloric acid, and so on).

The finest table salt is usually packed in 2-lb cardboard cartons. Ordinary grades are shipped in 2-, 5-, 10-, 25-, or 50-lb cloth sacks and in the standard 280-lb barrel. A considerable quantity is also sold in bulk.

Salt is sold both directly to large consumers and indirectly through wholesalers, jobbers, and retailers.

Since salt is sold on a delivered-price basis and since there are so many different types of packing as well as bulk shipments and sales in brine form, no simple statement of prices is possible. In 1946 the average value at the point of production of all salt produced was under \$3 per ton; rock salt averaged about \$4; evaporated salt, nearly \$8 per ton; and pressed blocks, nearly \$9. The low total average was due to the low price realized from the value of salt sold or used in brine form. Details of marketing and pricing are given by Phalen¹⁸ and Harris.¹¹

Specifications and Tests. The grades, sizes, and specifications for salt for various uses have been discussed by Phalen, from whose work the following is quoted:

The different kinds of salt are vacuum-pan, grainer, open-pan, solar, and rock salt, depending on the method of production or origin. These different types of salt may be used for the same purposes, but obviously certain types are better adapted for a specific purpose than are others. Vacuum-pan salt, by virtue of its fineness and purity, is particularly suitable for table and dairy purposes. It is better known in the trade as "granulated."

The salt produced according to the other methods mentioned may be graded and sold in the two most common sizes, known as common fine (C.F.) and common coarse (C.C.). Undried salt, whether made in vacuum pan or grainer, is usually termed common fine, and salt produced by these two methods when dried and sifted is classed

TABLE 6. SALT SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY CLASSES AND USES, SHORT TONS

Use	1945				1946			
	Evapo- rated	Rock	Brine	Total	Evapo- rated	Rock	Brine	Total
Chlorine, bleaches, chlorates, etc....	347,700 ^a	644,916	1,540,359 ^a	2,532,975	337,513	594,659	1,454,682	2,386,854
Soda ash.....	^b	.....	7,087,227	7,087,227 ^b	.....	.....	6,957,592	6,957,592
Dyes and organic chemicals.....	58,101	41,460	.....	99,561	56,991	53,547	.....	110,538
Soap (precipitant).....	50,141	18,862	^c	69,003 ^c	48,412	15,185	.....	63,597 ^c
Other chemicals.....	105,363	441,579	^c	546,942 ^c	104,484	430,987	^c	535,471 ^c
Textile processing.....	35,968	101,378	.....	137,346	37,505	121,176	.....	158,226
Hides and leather.....	105,227	161,049	.....	266,276	108,029	178,083	.....	286,112
Meat packing.....	362,202	360,744	.....	722,946	354,365	331,482	.....	685,847
Fish curing.....	36,123	71,571	.....	107,694	37,856	35,307	.....	73,163
Butter, cheese, and other dairy products.....	112,087	5,592	.....	117,679	121,447	5,647	.....	127,094
Canning and preserving.....	156,713	16,164	.....	172,877	167,249	21,725	.....	188,974
Other food processing.....	230,993	22,243	.....	253,236	240,799	24,885	.....	265,684
Refrigeration.....	45,449	235,904	.....	281,353	48,042	221,635	.....	269,677
Livestock.....	539,929	192,817	.....	732,746	599,537	192,344	.....	791,881
Highways, railroads, dust and ice control.....	10,149	307,656	.....	317,805	7,960	312,164	.....	320,124
Table and other household.....	472,106	210,175	.....	682,281	498,166	209,684	.....	707,850
Water treatment.....	179,544	196,842	^b	376,386 ^c	212,248	213,197	^c	425,445 ^c
Agriculture.....	42,753	14,013	.....	56,766	16,380	15,492	.....	31,872
Metallurgy.....	28,922	29,000	^c	57,922 ^c	17,566	31,403	.....	48,969
Undistributed ^d	263,100	433,775	78,245	775,120	235,363	403,406	58,406	697,175
Total.....	3,182,570 ^b	3,505,740	8,705,831 ^a	15,394,141	3,249,457	3,142,008	8,470,680	15,132,145

^a Revised figure.^b Data for evaporated salt included with Undistributed.^c Data for salt in brine included with Undistributed.^d Comprises miscellaneous uses and data not presentable by classes (footnotes b and c), including most exports.

as dairy salt. . . . Important factors entering into sales are color and moisture content. Moist salt may contain 4 to 5 per cent moisture. The four common grades in the eastern market are No. 1 common fine (C.F.), medium coarse (C.C.), coarse, and rock.

In New York, rock salt is produced in four market sizes, in addition to the large lumps direct from the mine. These, beginning with the coarsest, are known as No. 2, $\frac{1}{4}$ to $\frac{1}{2}$ in.; No. 1, $\frac{1}{8}$ to $\frac{1}{4}$ in.; C.C., $\frac{1}{16}$ to $\frac{1}{8}$ in.; and C.F., under $\frac{1}{16}$ in. The C.C. and C.F. salt produced by the different methods generally correspond in size.¹⁸

Phalen and Harris give the commercial grading used in other parts of the country, but they are similar to those noted above. They also give specifications for a few of the most important uses.

Utilization. The largest single use for salt is in the manufacture of other sodium salts, such as soda ash and caustic soda, and in making chlorine, hydrochloric acid, and other chlorine chemicals. Brine, rather than evaporated or rock salt, is generally used for this purpose. In 1946 over 55 per cent of the total United States salt production in all forms was brine used or sold for making these chemicals.

Table 6 shows the domestic salt production distributed by most important uses.

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SAND AND GRAVEL

Definition. Sand and gravel are unconsolidated aggregates of highly siliceous, usually quartzose grains, ranging in size from material as fine as clay to material ordinarily called boulders. The finer aggregates are known as sand and the coarser as gravel. It is apparent that there is a continuous gradation in size from the finest silt to the largest boulders, and various authorities differ as to just where the dividing lines should be drawn. The dividing line between sand and gravel is variously placed at from 0.1 to 0.25 in. There seems to be no definite upper limit to the size of gravel, but commercial gravels do not usually contain pebbles much larger than 2½ or 3 in. Siliceous aggregates of such fine grain size that individual grains cannot be distinguished by the unaided eye and in which the characteristic sandy texture is not evident are usually called silts.

There is a complete gradation in coherence from unconsolidated sands and gravels through partly indurated aggregates, friable sandstones, firm sandstones, and conglomerates, to metamorphosed sandstones or quartzites.

Composition. Most sands and gravels consist largely of quartz grains and pebbles, but commercial sands and gravels usually contain from very small to

considerable quantities of impurities, such as feldspar, mica, limonite and other iron oxides, tourmaline, garnet, titanite, zircon, calcite, dolomite, hornblende, and other minerals. For many purposes such impurities are not harmful, but sands for certain purposes, such as glass sand and molding sands, must conform to rather rigid chemical specifications.

Although the common sands of commerce are highly siliceous, there are other types that contain very little silica. Thus, there are garnet sands, black sands (consisting largely of heavy and often iron-bearing minerals, such as magnetite, chromite, titanite, rutile, spinel, and so on), monazite sands, glauconitic or "greensands," and so on.

Origin and Classification. Sands and gravels are always of secondary origin. They are formed by the disintegration of rocks, accomplished by both chemical and mechanical means. Some of the chief agencies are frost, rain, the sun's heat, the solvent action of acid or alkaline ground waters, and stream and wave action. Since silica is one of the most inert minerals, many of the other rock components are gradually dissolved or broken down to fine silt and carried away by flowing water, leaving deposits of more or less pure silica sand and gravel. This material is then usually transported, often over great distances; abraded; washed; sorted and classified by the action of streams, glaciers, waves, or winds; and finally redeposited in the forms in which they now occur. Most sands laid down by water in stream bed, lake, and beach deposits and most wind-blown deposits are bedded or stratified. Glacial deposits often show no bedding and little sorting, but certain types closely resemble stream or lake deposits.

Sands may be classified in many different ways, for example, by origin, by chemical or mineralogical composition, by geological or geographic distribution, by grain size, by uses, or by combinations of two or more of these methods. For the purposes of this discussion probably the classifications by origin, sizes, and uses are the most valuable.

The principal types of deposits based on origin are (1) river; (2) lake; (3) glacial; (4) beach; (5) aeolian (wind-blown). *Coral sand* consists of small fragments of corals and shells broken down and sorted by wave action. *Volcanic sand* or volcanic ash consists of finely divided material ejected from volcanoes (see Pumicite).

Various classifications of sands and gravels by size have been suggested. The classifications in Tables 1 to 3 are given by Condra, Dake, and Boswell.

TABLE 1. SIZES OF SAND*

Fine sand.....	0.5 mm or 0.02 in. in diameter
Medium sand.....	2.0 mm or 0.08 in. in diameter
Coarse sand.....	5.0 mm or 0.20 in. in diameter

* CONDRA, G. E.: Sand and Gravel Resources and Industries of Nebraska, Vol. 3, Pt. 1, p. 29, Nebr. Geol. Survey, 1908.

Classification by Uses. In any classification of sand and gravel by uses it should be noted that a sand or gravel may be suitable for a variety of uses and may be shipped and sold under several names. Stone* notes:

* STONE, R. W., Sand and Gravel, *Mineral Resources of the United States*, Pt. 2, p. 630, U.S. Geol. Survey, 1912.

TABLE 2. SIZES OF SAND AND GRAVEL USED IN MISSOURI*

Sand.....	Through $\frac{1}{8}$ in.
Torpedo gravel (or sand).....	Through $\frac{1}{4}$ in. on $\frac{1}{8}$ in.
Roofing gravel.....	Through $\frac{3}{4}$ in. on $\frac{1}{4}$ in.
Binder gravel.....	Through $1\frac{1}{2}$ in. on $\frac{3}{4}$ in.
Concrete gravel.....	Through $2\frac{1}{2}$ in. on $1\frac{1}{2}$ in.

* DAKE, C. L.: Sand and Gravel Resources of Missouri, Vol. 25, Second Series, p. 7, Mo. Bur. Geol. & Mines.

TABLE 3. SIZES OF SAND AND GRAVEL*

Grade	Sizes	Class
A	Greater than 2.0-mm diameter	Gravel
B	Greater than 1.0-mm diameter and less than 2.0-mm	Very coarse sand
C	Greater than 0.5-mm diameter and less than 1.0-mm	Coarse sand
D	Greater than 0.25-mm diameter and less than 0.5-mm	Medium sand
E	Greater than 0.1-mm diameter and less than 0.25-mm	Fine sand
	Greater than 0.05-mm diameter and less than 0.1-mm	Superfine sand or coarse silt
F	Greater than 0.01-mm diameter and less than 0.05-mm	Silt
G	Less than 0.01-mm	Clay or mud

* BOSWELL, P. G. H.: "Memoirs on British Resources of Sands Suitable for Glass making," Longmans, Green & Co., London, 1916, p. 16.

As an example, a New Jersey dune sand is sold to filtration plants for filter beds, to local masons for building or mortar sand, to foundrymen for core sand, and might be used for engine sand, paving sand, or other purposes. Gravel also assumes various names, depending on its use. One size of gravel is shipped from one plant for filter beds, sand blast, roofing, concrete, and asphalt paving. A high-grade silica sand is glass sand to a glassmaker, steel sand to a steel molder, grinding sand to a stonecutter, asphalt sand to a pavement contractor, facing sand to a concrete-block maker, and furnace sand to a foundryman.

The following classification of sands by uses is mainly that given by Stone,* but with several additions:

Asphalt sand is the term used by some producers to designate a clean siliceous sand of medium grain and sharpness used for mixing in the body and making the face of asphalt pavement and asphalt paving blocks.

Bedding sand is scattered over the floor of cattle cars for sanitary purposes. Any fine, clean sand is suitable.

Blast sand is clean, tough, sized sand, either round or angular grains, used by means of compressed air for such purposes as cleaning metal castings and dressing stone.

* *Op. cit.*

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Brass sand is an exceedingly fine sand used in making molds for casting aluminum, brass, and bronze on which a very smooth surface is desired. It has a strong bond, but is so fine-grained that its permeability is slight and care has to be taken to avoid "blowing."

Building sand is used for making mortar and concrete and sand-lime brick. For best results it should be siliceous, clean, free from salts, as sharp as can be obtained at a reasonable cost, and dry; and it should not contain more than 10 per cent by weight of clay or loamy material. Sand used for mortar should pass a No. 10 sieve and 80 per cent of it should be retained on a No. 74 sieve.

Burnishing sand is a fine-grained, clean, tough, silica sand, with grains as nearly round as possible, used in rolling down and burnishing gold decorations on chinaware and porcelain. It should be very uniform in size; a sand in successful use practically all passes a 65-mesh screen and is retained on a 100-mesh screen.

Core sand is a coarse molding sand used to make a solid form, usually porous, to be placed in a mold, about which the metal is poured, so as to be cast hollow. Permeability is the special quality required.

Engine sand is used on locomotives and streetcars to keep the wheels from slipping on wet or slick rails. The principal requirements are that the sand be of hard minerals, preferably quartz—sharp, clean, dry and fairly fine and even-grained, so that it will run freely through the conductor pipe.

Facing sand is a molding sand used to make the face of the mold, the term being used when the material composing the face is different from the body of the mold. Sand used for facing the mold of a heavy casting may be equally well adapted for making the entire mold for a lighter casting.

Mortar sand is building sand used particularly for making mortar.

Filler sand is used as an inert filler in certain types of prepared fertilizer. Any fine-grained clean sand may be used.

Filter sand is clean silica sand in sorted sizes, used for beds in water-filtration plants and in small mechanical filters. It must be free from lime, clay, and organic matter.

Fire sand is a highly refractory silica sand for lining furnaces and ladles used to contain molten metal.

French sand is a very fine, open, sharp, yellow sand imported from France for making molds for statuary, brass, and bronze work.

Furnace sand is a highly refractory silica sand used for lining and patching reverberatory and other furnaces, cupolas, and ladles used to contain molten metal. Since pure silica sand is noncohesive, some binder is added to give bond. Furnace sand is also used for making runners for pig-iron casting.

Glass sand is the major constituent of glass, constituting from 52 to 65 per cent of the original mixture. Since the quality of the glass depends largely on the quality of the sand, high-grade glass sands are over 99 per cent silica (SiO_2). Glass sand should be nearly white in color, of medium fineness (passing a 20- to 50-mesh horizontal sieve), the grains should be uniform in size, even, and angular; or, less preferably, they may be rounded.

Grinding and polishing sands are sharp, tough, hard sands free from clay or foreign material and sized, for use in sawing, cutting, and polishing stone and for grinding and etching glass. The size of the sand varies with the character of the material to be worked on and the kind of work to be done.

Molding sands are siliceous sandy materials used in foundries for making molds and cores for casting metal. They vary from loamy clay to clean silica sand or gravel, the character of the material used depending on the kind of metal to be poured, the size of the casting, the surface desired, and the place in the mold where the sand is to

be used. Molding sands should be high in silica to be sufficiently refractory, should have a strong bond when moist, and should have less than 1 per cent of iron oxide. Some molding sands lack bond and are tempered by the addition of a small amount of clay or other binding material. Sand used for dusting brick molds to aid in separating the brick from the form is called molding sand, but should more properly be termed a "parting sand" to distinguish it from foundry molding sands.

Parting sand is a noncohesive sand with which the meeting faces of a mold are dusted to prevent their sticking together and with which brick molds are dusted to aid in separating the form from the mold. It is a fine sand free from clay.

Paving sand is a designation applied to sand used in various ways in road and walk making. Besides the common use on country roads, sand is used for the cushion foundation for brick pavement, as the body and facing of asphalt paving, as part of the composition of concrete and cement walks, as bedding for cobble pavement, and in other ways. For some of the uses almost any convenient sand is suitable, but for others special properties are required (see paragraphs on asphalt and building sand).

Railroad-ballast sand and gravel have usually but one requirement: bulk, although coherence is a desirable quality. Sand and gravel that will pack and set are preferable. For surfacing tracks, gravel or crushed stone is used to reduce the amount of dust raised by passing trains, and in some places to keep the material from being carried away by high winds.

Sand-blast sand. See blast sand.

Silica sand is composed largely of quartz and is obtained from banks of unconsolidated material and by crushing sandstone. It is used for many purposes, including making glass; lining furnaces and ladles; molding steel; filters; facing concrete and asphalt; as an abrasive (both sand blast and sandpaper); and for firebrick, scouring soap, etc.

Silver sand is a term used in England for a fairly pure, fine, white sand used mainly for scouring and for lightening soil.

Steel sand is a molding sand used for casting steel. A high degree of refractoriness is required, and therefore a white, clean quartz sand about 99½ per cent silica is used. Since sand of this character has no bond, in order to make a mold with it a small quantity of siliceous clay, molasses, or other material is added for binder. The size of grain used varies with the weight of the casting and the place occupied in the mold.

Torpedo sand is a trade term used locally in the central states for a coarse building sand.

Other uses to which sand and gravel are put are for chicken grit, pebble dash, sandpaper,* sanding woodwork, sand-lime brick, etc.

Standard sand is a clean, even-grained, uniform, high-grade silica sand used as a laboratory standard in physical tests of other sands or cements. For example, in testing the value of a sand for concrete aggregate, the unknown sand and the standard sand are tested under the same conditions, and the results are compared. Such a testing sand must possess absolute uniformity of physical characteristics over a long period of years. In the United States, high-grade sand from Ottawa, Ill., is used for this purpose.

Artificial or manufactured sands and gravels are of importance in some localities. These may consist of mill tailings from ore-concentrating plants, such as

* Sand is now little used for sandpaper, because the grains are not sufficiently sharp. Crushed quartz or flint is generally used for this purpose.

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TABLE 4. SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY COMMERCIAL AND GOVERNMENT-AND-CONTRACTOR OPERATIONS AND BY USES

	1945			1946			Per cent of change in	
	Short tons	Value		Short tons	Value		Ton-nage	Avg value
		Total	Avg		Total	Avg		
Commercial Operations								
Sand:								
Glass.....	4,681,920	\$ 8,374,218	\$1.79	4,848,602	\$ 9,541,405	\$1.97	+3.6	+10.1
Molding.....	7,190,856	9,724,750	1.35	6,973,906	9,531,263	1.37	-3.0	+1.5
Building.....	30,490,146	19,812,208	0.62	48,237,949	31,653,529	0.66	+58.2	+6.5
Paving.....	16,681,521	10,428,371	0.63	24,360,044	16,373,892	0.67	+46.0	+6.3
Grinding and polishing ^a	542,511	1,029,501	1.60	906,889	1,379,954	1.52	+41.1	-5.0
Fire or furnace.....	308,997	387,872	1.26	248,866	333,643	1.34	-19.5	+6.3
Engine.....	2,771,896	1,924,725	0.69	2,797,132	1,924,779	0.69	+0.9	
Filter.....	109,845	231,026	2.10	157,511	284,991	1.81	+43.4	-13.8
Railroad ballast ^b	1,082,626	400,762	0.37	714,884	262,089	0.37	-34.0	
Other ^c	1,116,353	1,117,153	1.00	1,548,620	1,747,921	1.13	+38.7	+13.0
Total commercial sand.....	65,076,671	\$ 52,430,586	\$0.81	90,794,403	\$ 73,033,466	\$0.80	-39.5	-1.2
Gravel:								
Building.....	27,910,042	\$ 21,735,554	\$0.78	40,424,515	\$ 32,958,822	\$0.82	+44.8	+5.1
Paving.....	36,759,164	25,693,994	0.70	46,894,010	34,325,134	0.73	+27.6	+4.3
Railroad ballast ^d	20,657,982	9,518,328	0.46	12,009,960	6,341,133	0.53	-41.9	+15.2
Other ^e	1,734,439	1,043,910	0.60	1,969,678	1,438,147	0.73	+13.6	+21.7
Total commercial gravel.....	87,061,627	\$ 57,991,786	\$0.67	101,298,163	\$ 75,063,236	\$0.74	+16.4	+10.4
Total commercial sand and gravel..	152,138,298	110,422,372	0.73	192,092,566	148,096,702	0.77	+26.3	+5.5
Government-and-contractor Operations ^f								
Sand:								
Building.....	1,018,000	\$ 428,000	\$0.42	894,000	\$ 313,000	\$0.35	-12.2	-16.7
Paving.....	5,631,000	1,998,000	0.35	4,752,000	1,629,000	0.34	-15.6	-2.9
Total government-and-contractor sand.....	6,649,000	\$ 2,426,000	\$0.36	5,646,000	\$ 1,942,000	\$0.34	-15.1	-5.6
Gravel:								
Building.....	2,145,000	\$ 1,225,000	\$0.57	2,752,000	\$ 1,416,000	\$0.51	+28.3	-10.5
Paving.....	34,592,000	14,764,000	0.43	53,641,000	19,932,000	0.37	+55.1	-14.0
Total government-and-contractor gravel.....	36,737,000	\$ 15,989,000	\$0.44	56,393,000	\$ 21,348,000	\$0.38	+58.5	-13.6
Total government-and-contractor sand and gravel.....	43,386,000	18,415,000	0.42	62,039,000	23,290,000	0.38	+43.0	-9.5
Commercial and Government-and-contractor Operations								
Sand.....	71,726,000	\$ 54,856,000	\$0.76	96,440,000	\$ 74,975,000	\$0.78	+34.5	+2.6
Gravel.....	123,798,000	73,981,000	0.60	157,691,000	96,441,000	0.61	+27.4	+1.7
Grand total.....	195,524,000	\$128,837,000	\$0.66	254,131,000	\$171,386,000	\$0.67	+30.0	+1.5

^a Includes blast sand as follows—1945: 318,390 tons valued at \$766,013; 1946: 292,899 tons, \$736,819.

^b Includes ballast sand produced by railroads for their own use as follows—1945: 17,792 tons valued at \$2,429; 1946: 83,422 tons, \$10,562.

^c Includes some sand used by railroads for fills and similar purposes as follows—1945: 220,244 tons valued at \$44,356; 1946: 164,061 tons, \$30,658.

^d Includes ballast gravel produced by railroads for their own use as follows—1945: 8,587,465 tons valued at \$2,987,940; 1946: 4,077,115 tons, \$1,640,726.

^e Includes some gravel used by railroads for fills and similar purposes as follows—1945: 843,969 tons valued at \$133,494; 1946: 736,462 tons, \$107,938.

^f Approximate figures for states, counties, municipalities, and other government agencies directly or under lease.

"chats" from the Tristate zinc district, screened and graded fines from crushed stone plants, and granulated slag from smelters and blast furnaces.

Distribution and Production. Deposits of sand and gravel occur in practically every state in the United States and in every country in the world. Sands of the lower grades are so abundant and so widespread that they are usually mined very close to the point of consumption. Higher grades of sand, however, such as glass sand, molding sand, filter sand, and special types for other purposes, are not so widely distributed and occasionally may be transported considerable distances. As an example the use of Belgian glass sand in California glass plants may be noted. Even the higher grades of sand are of relatively low unit value, however, and only under exceptional circumstances can high transportation charges be paid.

Thus, sands and gravels do not enter largely into import or export trade. Glass sands are sometimes imported, as well as certain types of foreign molding sands, which are still preferred by some conservative users, despite the fact that domestic sands of equal or better grades are available. Low-grade sands of foreign origin sometimes enter the ports of this country as ballast, and there is some local movement of sands across the Canadian border in both directions. Generally speaking, international trade in sand and gravel is of little importance. Production is governed chiefly by local demand and car supply, and the shipping radius is determined by freight rates. There is little need, therefore, of even noting producing localities, except for certain special grades of sand.

Tables 4 and 5 from the U.S. Bureau of Mines "Minerals Yearbook" show the most important facts of these industries in recent years.

TABLE 5. SAND AND GRAVEL SOLD OR USED BY COMMERCIAL AND GOVERNMENT-AND-CONTRACTOR PRODUCERS IN THE UNITED STATES, 1944 TO 1948

Year	Sand		Gravel (including railroad ballast)		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944	68,978,000	\$54,054,000	125,805,000	\$71,110,000	194,783,000	\$125,164,000
1945	71,726,000	54,856,000	123,798,000	73,981,000	195,524,000	128,837,000
1946	96,440,000	74,975,000	157,691,000	96,411,000	254,131,000	171,386,000
1947	108,719,000	94,154,000	178,940,000	122,715,000	287,659,000	216,869,000
1948	118,661,000	107,915,000	200,605,000	144,583,000	319,266,000	252,498,000

The production of sand and gravel in 1946 reached 254,131,000 short tons valued at \$171,386,000, an increase of 30 per cent in quantity and 33 per cent in value over the 195,524,000 tons valued at \$128,837,000 reported in 1945. The largest increases were reported for sand and gravel utilized in building, which reflect the great expansion of the construction industry.

California in 1946, as in 1945, was the largest producer, and Illinois, Michigan, Wisconsin, Ohio, New York, Texas, Minnesota, and Pennsylvania follow in that

order. These nine states, each with an output of more than 10 billion tons, accounted for 52 per cent of the total production. Table 5 shows details of production, by states and uses, in 1946.

Imports of sand and gravel in the period from 1937 to 1946 ranged from 276,000 to 701,000 short tons, nearly all of which came from Canada. Glass sand imports dwindled from about 51,000 tons in 1937 to zero in 1941. Imports were resumed in 1946 with about 5,000 tons, all from Belgium and Luxembourg.

Some of the best known localities in which deposits of high-grade sand for glassmaking and other purposes occur are as follows: *Illinois*, Ottawa and Utica; *Indiana*, Michigan City; *Maryland*, Hancock; *Michigan*, Rockwood (optical-glass sand); *Missouri*, Crystal City, Klondike, and Pacific; *New Jersey*, Cedarville, Millville, and South Vineland; *Ohio*, Austintown, Chalfonts, Massillon, and Toboso; *Pennsylvania*, Falls Creek, Lewistown, Mapleton, Parrish, and St. Marys; *Virginia*, Kermit and Mendota; *West Virginia*, Berkeley Springs, Great Cacapon, Hancock, Sturgisson, and Thayer.

A few of the famous foreign localities are noted below. In *France*, at Fontainebleau near Paris, there are deposits of very high-grade glass sand, which have been noted throughout the world for its high quality for many years. At Fontenay aux Roses, near Paris, there has been produced for many years a high-grade molding sand peculiarly well adapted for the making of molds for fine brass and bronze castings.

In *Germany* the famous Lippe glass sand, one of the purest known, occurs near Dörentrop in Saxony. High-grade glass sand also occurs at Hohenbocka in Prussia.

General Aspects of the Sand and Gravel Industry. Sand and gravel are very common, bulky materials of low unit value. Nearly all varieties of sand occur in large quantities. Thus, with but few exceptions, sands and gravels in the ground have relatively little intrinsic value. Market values are derived from the costs of mining, preparing and transporting the material to the point of consumption. Even deposits of high-grade glass sand are of little value if they are situated far from actual or potential centers of glass production that may be supplied from nearer sources, or if the deposit is in a district where sands of equal grade are very abundant.

The important factors that should be carefully considered before developing a new deposit of sand or gravel are (1) purity of the sand; (2) its physical characteristics; (3) uses for which it is suited; (4) conditions of mining or quarrying; (5) need for washing or other preparation; (6) availability and price of fuel if drying is necessary; (7) availability of water for washing; (8) location of deposit with respect to good transportation facilities; (9) distance to important consuming centers not already adequately supplied.

For most sands and gravels probably the last two factors are of greatest importance. Adequate transportation facilities are vital, for high freight rates, car shortages, and poor railroad equipment have often made the operation of sand plants almost impossible. It is very desirable that deposits be served by two or more transportation routes, the more the better, in order that competition may assist in providing favorable freight rates and reduce the severity of car shortages.

When prices become too high, due to freight rates, and deliveries are held up, due to car shortages, many small roadside pits served by wagons or motor trucks are placed in operation, and the large, well-equipped plants lose their markets.

Sand and gravel operations today, particularly those which furnish building sands and concrete aggregates for structural purposes in the large cities, are often conducted on a very large scale. Investment for machinery and equipment is heavy and daily production is large. Competition is often keen, and prices are held down so that efficient operation is necessary if the operations are to be profitable.

Mining and Milling. Sands and gravels are removed from the ground and prepared for market by such a great number and variety of methods that detailed descriptions cannot be given here. Mining and milling operations vary in size and complexity from the simple roadside pit, where a few tons a day are loaded by hand methods without any form of milling, to very large plants, where thousands of tons of sand and gravel are excavated, washed, and sized each day. Some of the largest milling plants in the country are at sand and gravel operations. For example, in 1946 there were 12 plants in the United States that produced over 1 million tons each and 48 plants producing over 500,000 tons per year (22 per cent of total United States tonnage).

Sands and gravels occur in unconsolidated surface deposits with or without overburden, in river and lake deposits under varying depths of water, in beach deposits, in bars in shallow water in rivers, and along sea coasts as loosely consolidated sands or as friable sandstones.

Methods of excavation are many and varied, depending upon the nature of the deposit and the size of the operation. Equipment used includes hydraulic giant; power shovel; excavator crane; dragline and power scrapers; hydraulic, grapple, ladder, and dipper dredges; and bulldozers. If either the overburden or the deposit itself are indurated they may have to be drilled and blasted. The excavated material may be transported to the preparation plant by motor truck, conveyor belt, pump and pipe line, sluice, barge and tug, cars and locomotive, or cars and cable. Since the literature of the subject is extensive and easily accessible no attempt will be made to cover it here.^{21,22,23}

Milling operations vary almost as widely as mining methods. Some deposits contain material sufficiently pure and uniform so that it may be shipped and used without washing or screening. This is often the case where sand or gravel is produced for some of the low-grade uses. Where milling is necessary, the methods used range from simple hand screening at small operations to very large washing, sizing, and drying plants where many sizes and grades of sand and gravel are produced in large quantities. At most large operations the product is at least sized and is often both washed and sized, in order that uniform, high-grade products may be shipped.

Where the material is mined dry and only sizing is necessary, the milling plant consists simply of a series of revolving screens (trommels), shaking screens, or inclined vibrating or impact screens.

Specifications for sand and gravel for important uses have become increasingly rigid, especially for such concrete structures as the Grand Coulee Dam, and the

preparation of these materials has become increasingly elaborate. Thus most sand and gravel produced in large plants is wet milled. Sand is separated from gravel by wet screening in trommels or electrically vibrated or mechanically shaken screens. Fine sand is separated from clay and from coarser sand by various types of intermittent or continuous wet classifiers. Strongly adhering clay is removed in screw washers resembling log washers or in cylindrical or conical revolving washers called "scrubbers." Gravel must be freed from shale, soft sandstone, coal, and other structurally weak materials. This may be done by breaking the soft materials without crushing the harder pebbles, in various types of special crushers, and removing them by washing or screening. They may also be removed by jigging or tabling, as in coal practice.

The cleaned sand and gravel is separated into commercial sizes, sometimes followed by blending of sizes to produce specification materials.

For some uses sand and gravel, after simple draining, may be shipped wet. For other uses, such as glass sand and engine sand, the product must be dried before shipment. This may be done in rotary driers, direct- or indirect-heat types, fired with coal, oil, or gas. Stationary, gravity flow, steam-coil driers may also be used, as in some glass-sand plants. Fettke has described this drier as follows.

Steam driers are usually built in sections about 20 ft long, 8 ft wide, and 6 ft high, with hopper-shaped bottoms. The walls of the drier are built of ordinary red brick. Inside are horizontal steam pipes resting on inverted angle irons. These pipes are arranged in tiers, one above the other, and are placed closer and closer together towards the bottom of the drier. The sand is discharged onto these pipes from a belt conveyor running over the drier, gradually drops down between them, and finally is discharged onto another belt conveyor at the bottom of the drier. The pipes are heated by passing steam through them.

The evaporated moisture is drawn off by means of an exhaust fan. After the glass sand is dried, it is screened so that the final product will pass a 14- to 22-mesh screen (18-mesh most common) and elevated to storage bins ready for shipment.

In the preparation of glass sand, where very low iron is essential, high-intensity magnetic separation concentrating tables and flotation have been used. High-quality sand of glass-sand grade is finely ground in tube or Hardinge conical mills with air separation to make potter's flint and fine-ground silica for filler and other uses (see Quartz and Silica).

Markets and Prices. In commercial sand and gravel operations 85 to 90 per cent or more of the total product sold has been prepared by screening or washing or both, while in government-and-contractor operations over 80 per cent is used in unprepared condition. Preparation adds from 60 to over 100 per cent to the sales value. Thus, in 1946 the average value of commercial unprepared sands and gravels was 50 cents per ton and that of prepared material 80 cents per ton. In government-and-contractor operations these values were 30 cents and 70 cents, respectively.

Sands and gravels in large quantities are usually either mined by the consumer or marketed directly from the producer to the consumer. The chief exception to this is the handling of building sand and gravel by retail dealers in building sup-

plies in small cities. Since most sands and nearly all gravels are widely distributed and of low unit value, they cannot stand high transportation charges, and markets close to the deposits must be sought. High-grade sands, such as glass, molding, and filter sands, however, may sometimes be shipped long distances. For example, deposits of high-grade glass sand are scarce in California, and Belgian glass sand is the cheapest high-grade material available.

The prices received for sand and gravel vary considerably according to grade and type, extent of competition, distance to markets, and so on.

Specifications and Tests. For nearly all the important uses of sand and gravel today there are definite specifications, often involving special testing methods. These specifications and tests are usually set up by the producing or consuming industries through their associations, such as the American Foundrymen's Association and the National Sand and Gravel Association, often in cooperation with the American Society for Testing Materials and the National Bureau of Standards. Other governmental and state bureaus and commissions that are large users of sand and gravel also do much research on the properties of these materials and set up their own specifications and methods of testing. The subject, with all its ramifications, is far too extensive to be covered adequately here.

For many uses the chemical composition of sand and gravel is not important, as for railway ballast and fill. For some special sands, such as glass sand, foundry sand, and filter sand, chemical composition is of great importance. For gravel for concrete aggregate the presence of chemically reactive impurities is objectionable. For most tonnage uses, however, physical properties are of greatest importance.

The most important physical properties and tests of sand and gravel are noted below (see also Refs. 10, 12, 20, and 23):

Color is usually not an important factor except in glass sands, where it is an index of purity.

Cleanness usually means relative freedom from clay, silt, and organic matter. It is controlled largely by washing.

Grain size, a very important factor, is determined by sizing on a series of standard wire sieves. Standard screen-opening ratios and methods of testing are specified for materials for various uses.

Effective size is the term used to denote a certain grain size when 10 per cent of the sand grains are smaller and 90 per cent are larger than that size. It is determined by plotting the curve of the screen analysis or by calculation and interpolation in such screen analysis expressed in percentages. The effective size is used in determining the uniformity coefficient and it also serves as an index of the coarseness of a sand.

Uniformity coefficient is a term used to express the uniformity or variation in grain size of a sand. It is determined by making a screen analysis of a sand and then finding the certain size of grain, compared with which 60 per cent of the sand grains are smaller and 40 per cent are larger. This may be done by plotting a curve of the screen analysis or by interpolation. This grain size is then divided by the effective size of the sample and the result is the uniformity coefficient. A coefficient only slightly greater than 1.0 indicates that nearly 50 per cent of the

sand grains are of the same size; a coefficient of 5 or 6 indicates considerable variation in size.

Shape of grain is important for many purposes. Sand grains may vary from very sharp and angular to almost perfectly round.

Soundness of grain is important for most uses. Grains should be sound and tough and show no evidences of disintegration.

Specific gravity of pure quartz sands is usually about 2.60 to 2.65. It may be determined by any of the standard methods. A low specific gravity usually denotes impurities or porosity of individual grains.

Voids. The percentage of voids or pore spaces between grains is dependent upon the shape of grains, the relative proportions of grains of different sizes and the degree of compactness and of grading. It may be determined in several ways. Such determinations are important for sands and gravels used for concrete, for molding sands, and so on.

Weight of sand is dependent upon specific gravity and percentage of voids. It is usually expressed in pounds per cubic foot or per cubic yard. The weights of sand vary from 2,200 to 4,000 lb per cu yd (average about 2,665 lb); and of gravel, from 2,200 to 4,200 lb per cu yd (average about 2,820 lb). Probably most of the values reported over 3,000 lb represent weights of wet material.

Refractoriness is that property which enables a sand to undergo high temperatures without fusing or breaking down. Refractoriness is lowered by the presence of such fluxes as lime, iron oxide, magnesia, and the alkalies. It is important in foundry sands, furnace sands, core sands, and other sands subjected to heat.

Other Properties. In addition to the properties noted above, sands for certain uses are subjected to other special tests.

Properties of Sands for Certain Important Uses. *Glass Sands.* Glass sands must be thoroughly dried before use. They must consist essentially of pure-white quartz grains free from clay, organic matter, and similar impurities. They must be uniform in chemical composition, and uniformity in size and shape of grains is very desirable. Glass sands should not be coarser than 20 or 30 mesh nor finer than 100 to 120 mesh. Coarse sand requires too high a temperature and too much time for fusion; very fine sand may be carried away by the draft in the melting furnace; silica dust does not melt readily but "balls up" and causes "seeds" and similar imperfections in the glass. Some glassmakers prefer sand grains of angular shape, for such sands melt more readily than those with well-rounded grains; this requirement is not always insisted upon. Freedom from clay and silt is necessary, since such impurities cloud the glass.

The percentage of iron which may be allowed in a glass sand depends upon the quality of glass to be produced. In general the tendency is for users to require lower and lower iron content in their raw materials, both because quality standards for their own products have risen and because the better producers of glass sand have been able to make products of increasing purity. Thus, older specifications are often no longer considered adequate. Some of the container glass today is in many respects equal in quality to some of the older high-grade tableware.

Individual consumers have their own standards of quality and sometimes use

grades of sand that do not conform to the highest standards because of price and availability. Thus, glass-container plants in California use local sands that are higher in iron and alumina than is acceptable by eastern standards.

Weigel²³ has determined the composition of several well-known glass sands, as given in Table 6 with one addition. The analyses in Table 6 are old, and it is probable that present products are somewhat purer.

TABLE 6. CHEMICAL COMPOSITION OF GLASS SANDS

Source	Per cent					
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Igni- tion loss
Crystal City, Mo.:						
Crude.....	99.405	0.210	0.075	0.072	0.068	0.170
Washed.....	99.78					
Mapleton, Pa.....	99.82	0.12	0.017	Trace	Trace	
Hancock, W.Va.....	99.81	0.17	0.014	0.00	0.00	
Ottawa, Ill.....	99.607	0.160	0.021	0.050	0.03	0.08
West Vienna, N.Y.....	98.6	0.17	0.23	.....	Trace	
Corona, Calif. (16).....	94.5-96	2.5-3.5	0.03-0.04	1.8-2.3*		

* K₂O, Na₂O, etc.

Some years ago the National Bureau of Standards and the American Ceramic Society proposed standard specifications for glass sand. These were not generally accepted or used by the industry but are of some value to indicate general tendencies. They are here included as Table 7.

In order to neutralize the color of the small amount of iron always present in glass sand and other raw materials, small amounts of "decolorizers" are added to the glass batch. These decolorizers are oxidizing agents and their action is to oxidize the iron compounds from the ferrous state (which imparts a bluish-green color to glass) to the ferric state (which imparts a light-yellow color). The principal decolorizer used is high-grade manganese dioxide; this can be used to neutralize not over 0.1 per cent iron oxide. Selenium is also used as a decolorizer in some types of glass.

Alumina was formerly considered an objectionable impurity in glass sands, but it is now intentionally added to some glass batches in the form of feldspar, lepidolite, and other minerals. If present in sand, its content should be uniform.

Calcium and magnesium oxides (CaO and MgO) are not objectionable if their content is small and does not vary much, for lime is one of the common constituents of most glasses.

Filter Sands. Filter sands are used in filtration plants for the purification of water. The sands are placed in uniform layers over layers of properly sized crushed stone or coarse gravel. The following specifications have been used for plants at Springfield, Mass., and Toronto, Ontario:

TABLE 7. PROPOSED CHEMICAL REQUIREMENTS FOR GLASS SAND
(Specification formulated by the American Ceramic Society in conjunction with the Bureau of Standards)

Qualities of glass	Silica (SiO_2)		Alumina (Al_2O_3)		Iron oxide (Fe_2O_3)		Calcium and magnesium ($\text{CaO} + \text{MgO}$)	
	Min percent- age	Toler- ance	Max percent- age	Toler- ance	Max percent- age	Toler- ance	Max percent- age	Toler- ance
First-quality optical glass.....	99.8	± 0.1	0.1	± 0.05	0.02	± 0.005	0.1	± 0.05
Second-quality flint glass containers, tableware.....	98.5	± 0.5	0.5	± 0.1	0.035	± 0.005	0.2	± 0.05
Third-quality flint glass.....	95.0	± 1.0	4.0	± 0.5	0.035	± 0.005	0.5	± 0.1
Fourth-quality sheet glass, rolled and polished plate....	98.5	± 0.5	0.5	± 0.1	0.06	± 0.005	0.5	± 0.1
Fifth-quality sheet glass, rolled and polished plate....	95.0	± 1.0	4.0	± 0.5	0.06	± 0.005	0.5	± 0.1
Sixth-quality green glass containers and window glass.	98.0	± 1.0	0.5	± 0.5	0.3	± 0.05	0.5	± 0.1
Seventh-quality green glass.....	95.0	± 1.0	4.0	± 0.5	0.3	± 0.05	0.5	± 0.1
Eighth-quality amber glass.....	98.0	± 1.0	0.5	± 0.5	1.0	± 0.1	0.5	± 0.1
Ninth-quality amber glass.....	95.0	± 1.0	4.0	± 0.5	1.0	± 0.1	0.5	± 0.1

The filter sand shall be clean sand, with either sharp or rounded grains. It shall be entirely free from clay, dust, or organic impurities, and shall, if necessary, be washed to remove such materials from it. The grains shall, all of them, be of hard material that will not disintegrate. The effective size shall not be less than 0.25 mm nor more than 0.35 mm. The uniformity coefficient shall not be more than 3.0. The sand shall be free from dust and shall not contain more than 1 per cent finer than 0.13 mm, and shall be entirely free from particles over 5 mm in diameter. The sand shall not contain more than 2 per cent by weight of lime and magnesia taken together as carbonates. In all other respects the sand shall be of a quality satisfactory to the engineer.

Foundry or Molding Sands. Foundry sands vary greatly in chemical composition and in grain size, uniformity, grain shape, and other physical characteristics, depending upon the mode of utilization. Thus, entirely different types of sand are needed for the casting of brass, aluminum, and steel. Much attention is now being given to the resources, production, preparation, and utilization of the different types of molding sands, by various technical societies, governmental agencies, and private laboratories, in order to develop larger and better sources of such sands and to promote more efficient preparation and use.

This is a very broad subject and can only be treated very briefly here. The following summary is given by Stone.

Foundry sand is an inclusive term for molding, core, and steel sands, all of which are properly described as molding sand because they are used in making molds for casting metal. Sand used to make a core in any particular mold differs so much from that employed in the rest of the mold that it is distinguished as core sand, while sand used as the core for a light casting may be equally well used for the mold of a heavier casting. Steel sands are so very different from ordinary molding sands that, although used for making a mold, they are given the more distinctive name.

The principal requisites of a molding sand are cohesiveness, refractoriness, texture, permeability, and durability. They may be discussed briefly as follows:

Bonding strength or cohesiveness is the quality of holding together. A slightly moistened molding sand tamped into a mold must hold together so strongly that when the pattern is removed the grains will stick together and preserve the shape of the pattern and also will resist the pressure of the molten metal when poured into the mold and its corrosive action while flowing in. Many core sands and all steel sands are deficient in cohesiveness or bond, and binder is supplied by the addition of clay, molasses, flour, or other material. Molding sands get their cohesiveness largely from the clayey material which they contain.

Refractoriness is infusibility or not melting when subjected to a high degree of heat. A molding sand must be so refractory that it will not melt or fuse and close the pores when molten metal comes in contact with it. The sand must remain sufficiently open to allow the gases to escape. Steel sand is subjected to so much higher heat than other molding sands that a very siliceous material is required, and therefore sand running above 97 per cent silica is used.

Texture in sand refers to the size of grain or percentage of grains of different sizes. This is an important quality in foundry sand, for it affects the cohesiveness and permeability, as well as determining to some extent the size and weight of casting that can be made and the character of the surface produced.

Permeability is the property which a sand possesses of allowing a gas or liquid to filter through it. This property depends on the size of the pores or open spaces between the sand grains. Porosity is the volume of pore space. This is not the same as permeability, for a sand having a few large open spaces through which a liquid or gas could easily escape may have only a small total pore space; on the other hand, a sand may have a large total pore space but be almost impermeable on account of the small size of the pores. Permeability is decreased by tamping, and sands of different-sized grains pack closer than those in which the grains are of the same size.

Durability in a molding sand is a desirable quality, especially when the sand used is expensive. A sand which dehydrates and loses its bond slowly or only after being used several times is preferred to one which burns out or becomes "dead" with one heating. Some sands can be used several times without treatment, and others can be used repeatedly by the addition of a small quantity of fresh sand.

Chemically, molding sands are siliceous and those used for ironwork commonly contain 76 to 85 per cent silica, 5 to 13 per cent alumina, less than 5 per cent iron oxide, rarely more than 4 per cent combined water, and usually less than $2\frac{1}{2}$ per cent lime and magnesia. A higher percentage of iron and lime is not objectionable in a sand for brass molding.

Since the principal requirement of a core sand is permeability and since a high alumina or clay sand fuses readily and stops the passage of gas or steam generated in casting, it follows that a core sand, as a rule, should be high in silica and low in alumina. While some sands and gravels in the raw state are adapted to use in cores of various sizes, it is common practice to make core sand by mixing ingredients. In many cases a highly refractory material suitable for a core sand is readily available and needs only the addition of a binder to make it usable. In the case of gravels for large cores, such as iron pipe, coherence or bond is obtained by the addition of loam, clay, or molding sand of strong bond. The permeability is sometimes increased by mixing rye straw in the core sand or by winding the core with rope made of swamp hay. In small cores it is customary to use coarse sand, which ensures sufficient permeability, and to add to it a small quantity of clay or molasses water for bond.

The principal requirement of steel sand is refractoriness because the temperature of molten steel is considerably in excess of the temperature of molten iron or brass. In order to obtain sufficient refractoriness, it is necessary to use almost chemically pure silica sand. The grain of the sand varies with the size of the casting and with the smoothness of surface desired. Ordinary glass sand, silica sand, and some furnace sands are adaptable to use in steel molding by the addition of a binder.

From the foregoing statements it will be seen that it is difficult to formulate a comprehensive definition of molding sand. The variety is great, ranging through many degrees of each of the required properties. Most molding sands are cohesive, some strongly so, but others are wholly lacking in this property and require the artificial addition of bonding material. Refractoriness varies from so low that a sand burns out with one using to so high that the sand can be used repeatedly. Permeability ranges widely and molding sands differ from coarse to exceedingly fine. The colors vary from white and yellow to brown and red.

Molding sand in place possesses for the most part relatively little intrinsic value. The cost of excavation and preparation makes the market value, to which must be added freight rates. Although many molders insist on sand from a particular locality, others are learning that sand equally well adapted to a special purpose can be obtained at several places. As a single example, molding sand for stove-plate work, which requires a smooth surface, is produced not only in the famous region of Albany, N.Y., but also at Zanesville, Ohio, Newport, Ky., and elsewhere. In some cases it is

cheaper to screen or bolt a local sand to get the desired grade than it is to pay freight on sand from a distance locality.*

Foundry sands are designated by grain fineness number, which is the screen mesh that all the grains would just pass if they were of uniform size—in other words, the weighted average fineness. Details of the methods of making this test are given in Refs. 10 and 20, and the classification of sands by this method is given in Table 8.

TABLE 8. GRAIN FINENESS CLASSIFICATION	
Grain Class	Sands with Grain Fineness Number
No. 1.....	200 to and including 300
No. 2.....	140 to but not including 200
No. 3.....	100 to but not including 140
No. 4.....	70 to but not including 100
No. 5.....	50 to but not including 70
No. 6.....	40 to but not including 50
No. 7.....	30 to but not including 40
No. 8.....	20 to but not including 30
No. 9.....	15 to but not including 20
No. 10.....	10 to but not including 15

With the progress in scientific methods in foundry practice less emphasis is now placed in getting a perfect natural molding sand for each purpose. Specification sands with the required properties are made from sands of the correct purity and grain size distribution by adding calculated amounts of bentonite or other suitable bonding clays. For the most recent and authoritative information on this subject the publications of the American Foundrymen's Association should be consulted.

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SAND-LIME BRICK

Definition. Sand-lime brick consists of sand bound together with a hydrated calcium silicate. It is made by mixing common silica sand with sufficient hydrated lime to coat each sand grain, molding into bricks under great pressure, and subjecting the bricks to a chemical "curing" process in contact with live

steam under pressure in hardening cylinders. Unless artificially colored, they are white in color, or nearly so, and have about the same hardness and porosity as common-clay building brick. They are characterized by unusually straight, uniform edges and plane, smooth surfaces. Sand constitutes about 85 to 95 per cent of the weight of the brick. An ordinary standard brick (size of common red brick) weighs about 5 lb.

Sand-lime products are not confined to common and face brick. An artificial stone (called "limestone") is made by the same process and is used for keystones, door and window sills, columns, capitals, and so on, and for decorative products, such as fountains and lawn ornaments. Sand-lime brick have also been used for enameled brick.

Raw Materials. *Sand.* The raw materials for sand-lime brick consist of silica sand and hydrated lime. The bond in the finished brick consists of amorphous monocalcium silicate containing a variable amount of water. This is formed by the action of steam on an intimate mixture of finely ground silica and calcium hydrate. The sand, therefore, has two functions: first, it must provide the aggregate; and, second, it must provide the fine-grained silica to enter into chemical combination with the lime to form the calcium silicate bond. The relative proportions of the fine and the coarse sand vary somewhat in practice, but, in general, about 15 per cent of the sand should pass a 100-mesh screen, and should be as much finer than 100-mesh as is economically possible. Few natural sands contain sufficient very fine material and usually at least part of the sand must be ground.

The remaining 85 per cent of the sand should so range in grain size that the percentage of voids be as low as possible. A relatively coarse sand is desirable and the upper limit in size for the large grains is about $\frac{1}{2}$ in. The coarse sand may be screened to remove large pebbles, and the screen oversize either discarded or crushed and returned to the screen. The sand should be reasonably clean and preferably angular in shape. The deposit should be near a market for brick and so situated that the sand may be cheaply mined. Dry deposits are preferable, for the sand must be fairly dry before use.

Lime. While a relatively small proportion of lime is used in sand-lime brick, its quality is of great importance. Emley states:

The lime must be perfectly hydrated before the bricks are pressed. Otherwise it will expand during the steam treatment and produce internal strains, which are frequently sufficient to disrupt the brick. The lime must also be sufficiently caustic to enter readily into combination with the sand.*

A high-calcium lime containing not over 5 per cent magnesia is required. The lime is used in the form of the hydrate and can be purchased as such, but most manufacturers prefer to buy lump lime and hydrate (slake) it themselves. This is due to the fact that perfect and complete hydration must be assured, and that it is generally cheaper to buy lime and hydrate it than to buy hydrated lime.

The lime may be hydrated either before or after mixing with the sand. Each

* EMLEY, W. E., "Manufacture and Properties of Sand-lime Brick," *Tech. Paper 85*, Natl. Bur. Standards, 1917, p. 13.

SAND-LIME BRICK

method has its advantages and its advocates, but more commonly the lime is hydrated alone before the sand is added. Great care must be taken in the hydration, and, while hydrators of the standard types are used in some plants, manufacturers sometimes prefer to use hydrators of their own design.

Proportions of Sand and Lime. The relative proportions of sand and lime used in practice vary somewhat, depending upon the percentage of voids and other physical properties of the sand and upon methods of manufacture. Up to a certain limit the greater the proportion of lime, the stronger the finished brick.

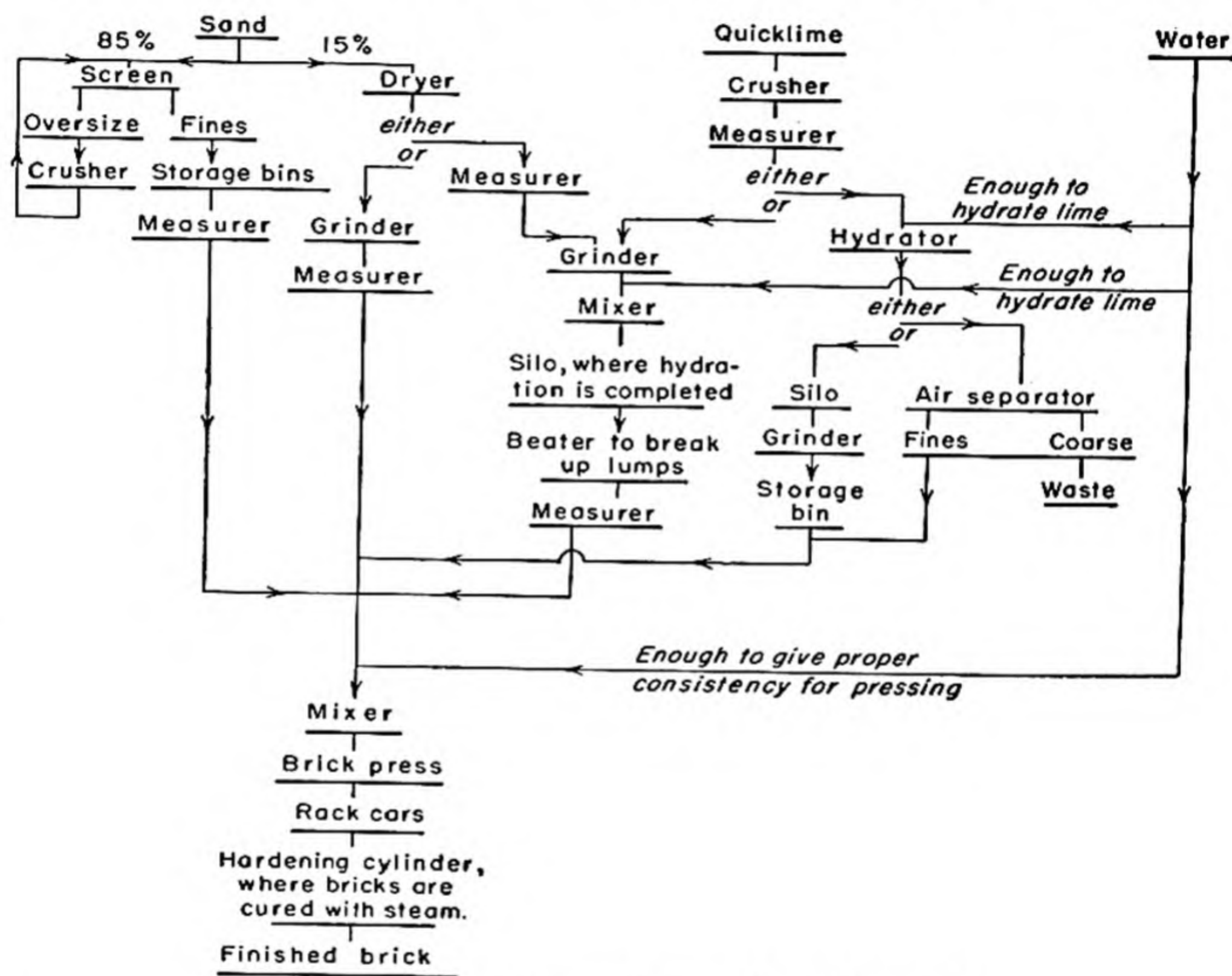


FIG. 13. Flow sheet of manufacture of sand-lime brick.

In actual practice, as little lime is used as is possible and still obtain the desired quality of brick, for lime is much more expensive than sand.

Experience has shown that small variations in the proportion of lime have little effect on the quality of the brick and often very crude methods of proportioning have been used. Emley states that:

The proportions of lime and sand actually put into the brick at different factories are usually one shovelful or wheelbarrow load of hydrated lime to four similar volumes of sand. The hydrate is therefore 25 per cent by volume of the sand. Assuming

that sand weighs 100 lb per cu ft and hydrated lime weighs 40, the hydrate is about 10 per cent by weight of the sand. If the hydrate carries 24 per cent water, the above proportions are equivalent to 7.6 parts of quicklime to 100 parts of sand by weight.*

Methods of Manufacture. The methods of manufacture used at various plants differ considerably in detail, but in general they follow the system outlined in the flow sheet shown in Fig. 13.†

Although sand-lime bricks made in different plants vary considerably in quality—that is, in compressive strength, absorption, behavior under heat, and so on—this is also true of clay brick. In general, it may be said that they are equal in quality to most clay brick and may be used for about the same purposes.

Sand-lime brick may often be made economically in localities where no brick is available and where freight rates on clay brick from distant producing centers are prohibitive. These are the most favorable conditions under which sand-lime brick manufacture may be conducted. In many districts where clay brick is readily available, sand-lime brick should compete on an equal basis. The capital investment required is comparatively small and the brick possesses the advantage of light color with good reflecting characteristics and little tendency to effloresce. It can be used as a substitute for the more expensive glazed brick for interiors. The regularity of color and the monotony of large walls may at time be unattractive. Crushed slate has been employed experimentally as a substitute for sand as described under Slate.

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* EMLEY, W. E., *op. cit.*, pp. 20-21.

† Adapted from flow sheet by W. E. Emley, *op. cit.* p. 4.

SERICITE

Sericite is a form of muscovite mica, produced as a secondary product by the alteration of alumina-containing minerals. It is characterized by the very fine, silky scales in which it occurs. Massive aggregates in which the true nature of the mineral is obscured are common. Chemical composition and physical properties are similar to those of muscovite except that it does not occur in large sheets and grains may be podlike instead of appearing as plates of uniform thickness.

Composition. Sericite has the theoretical formula $H_2KAl_3(SiO_4)_3$. Its percentage composition is SiO_2 , 45.2 per cent; Al_2O_3 , 38.5 per cent; K_2O , 11.8 per cent; H_2O , 4.5 per cent. Due to the ease with which other elements may be introduced in the crystal structure, material with a composition approaching the theoretical is rare.

Physical Properties. *Hardness*, 2 to 3. *Specific gravity*, 2.8 to 3.1. *Index of refraction*, 1.561 to 1.590. *Color*, colorless, grayish, yellowish, or reddish. *Luster*, silky. *Cleavage*, basal.

Occurrence. Sericite is a common constituent of metamorphic rocks. It is easily confused with illite and similar members of the mica family. It may be found in any environment where aluminous minerals, particularly the feldspars, have undergone alteration. It is frequently encountered as a selvage mineral associated with ore veins produced by hydrothermal waters. Because of its soapy nature it is often incorrectly identified as talc. A special type of sericite of unusual purity, found in Nevada, is described under Pinite. Extensive bodies of sericite schist occur in Lancaster County, Pa., and in many other areas.

Utilization. Sericite has been used in the manufacture of mullite refractories as noted under Pinite. Some of the material from Pennsylvania and other states has been washed, sized, and dried for use as ground mica. Ground sericite may not be considered an acceptable substitute for ground muscovite mica, even though it is of good color and free from grit and other impurities. While sericite, mineralogically, is a form of muscovite, it may grind to a thick, podlike flake that will not "plate" down in paint and wallpaper like the thin, flat, scaly flakes of true, water-ground mica. The presence of undesirable amounts of iron has excluded some sericites from use in the ceramic industries.

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SERPENTINE

Composition. Serpentine is a hydrous silicate of magnesium ($\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$), $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, and may contain iron and nickel. Its percentage composition is MgO, 44 per cent; SiO_2 , 44 per cent; H_2O , 12 per cent. Commercial deposits may run 37 to over 40 per cent MgO.

General Description. Serpentine is a common soft granular or fibrous mineral or rock mass, usually green in color; crystals unknown. A fibrous variety, chrysotile, is the most valuable type of asbestos (see page 39). An impure massive variety, verd antique, contains irregularly intermixed veins and patches of calcite, dolomite, or magnesite.

Physical Properties. *Hardness*, 2.5 to 4. *Specific gravity*, 2.5 to 2.8. *Index of refraction*, 1.508 to 1.590. *Color*, various shades of green to black, also yellowish, brownish, grayish, and reddish—often mottled. *Streak*, white. *Luster*, greasy, waxy, or silky. *Cleavage*, conchoidal to splintery fracture. *Transparency*, translucent to opaque. *Tenacity*, brittle except in chrysotile, the fibers of which are flexible and strong.

Occurrence and Production. Serpentine is a secondary mineral resulting from the alteration of magnesian rocks and minerals, such as olivine, enstatite, hornblende, tremolite, augite, and peridotite.

Occurrences of serpentine asbestos are noted under Asbestos. Massive serpentine, precious serpentine, or verd antique usually accompanies chrysotile asbestos. These varieties have also been quarried at Easton, Pa., at Milford, Conn., and in other localities. Serpentine is very abundant in many states and often accompanies commercial deposits of talc and soapstone. An extensive area reaches from Lancaster County in Pennsylvania into Baltimore County, Md. The tonnage available is very large. A number of quarries have been active in the past, but production of late years has been restricted to one producer. Underground mining has been employed to obtain sound blocks of desirable material overlain by heavy overburden. Production was started in California in 1946 to obtain serpentine for the manufacture of fertilizer.

Utilization. Translucent material of attractive color has been cut and polished and employed as a gem stone in a small way. It is too soft for general use. Large quantities of the massive dark-green variety have been quarried, cut, and polished in many forms and sold as green marble. The veined variety, verd antique, has been popular for mantles, table tops, vases, columns, and panels for exterior and interior ornamental purposes. It has been ground and sold as talc or "mineral pulp" for filler use. It does not exhibit upon prolonged exposure the permanence necessary in a building stone for exteriors. At the present time it is crushed and sized to proper dimension for use in terrazzo fillers and for roofing granules.

Considerable interest has been shown in the use of serpentine in the manufacture of refractories, and some tonnage is now so employed. The magnesia content is on the low side, for the production of refractories of the forsterite type and olivine has been considered more suitable. The production of fused phosphate

rock-serpentine fertilizers was begun on the west coast in 1946. The product "Thermo-Phos" is produced by the fusion of serpentine, of local origin, with phosphate rock from Idaho. It is reported to be suitable for direct application to the soil or for incorporation in mixed fertilizers. It provides in a readily available form a source of magnesia, an essential plant food lacking in some areas. Much work has been done on serpentine as a source of metallic magnesium and as the raw material for making epsom salts and other magnesium chemicals.

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SLATE

Definition. Slate is a fine-grained, metamorphic rock characterized by a more or less perfect cleavage in one direction, varying widely in color and mineralogical and chemical composition. It is differentiated from shale by greater hardness and coherence, by containing characteristic metamorphic minerals, and by the fact that the cleavage of slate bears no relation to the original bedding planes, while the cleavage of shale is usually parallel to the bedding planes.

Composition. Slate is not a mineral, but a rock of variable composition, containing several minerals, the most abundant of which are quartz, sericite mica, and chlorite mica. The mineralogical composition of an average slate, as given by Dale,⁶ is as follows:

MINERAL COMPOSITION OF AVERAGE SLATE

	<i>Per Cent</i>
Mica (sericite).....	38-40
Chlorite.....	6-18
Quartz.....	31-45
Hematite.....	3- 6
Rutile.....	1- 1½

Clay or kaolin is usually present in small amounts in mica slates and may be quite abundant in clay slates. Other minerals of minor importance are rutile, hematite, pyrite, carbonaceous matter, graphite, feldspar, zircon, tourmaline, calcite, dolomite, and siderite.

The chemical compositions of typical slates are shown in Table 1, quoted from Dale.

Origin. Nearly all deposits of slate have originated from sedimentary deposits consisting largely of clay. In a few instances slates have been formed from volcanic ash beds (for example, the green ash slates of the English lake district at Buttermere, Tilbertwaite, etc.) and from dikes of igneous rock (as at the

TABLE 1. SUMMARIZED ANALYSES OF ROOFING SLATES FROM NEW YORK, VERMONT, AND PENNSYLVANIA

	New York		Vermont					Lehigh County, Pa.	General average
	Bright green (1)*	Red (4)	Sea green (3)	Unfading green (2)	Variegated (Eureka) (1)	Purple (2)	Black (1)	Black (1)	
Silica (SiO ₂).....	67.89	63.89	63.33	59.37	60.24	61.29	59.70	56.38	61.51
Titanium dioxide (TiO ₂)...	0.49	0.52	0.73	1.00	0.92	0.77	0.79	0.78	0.75
Alumina (Al ₂ O ₃).....	11.03	11.80	14.86	18.51	18.46	16.24	16.98	15.27	15.39
Ferric oxide (Fe ₂ O ₃).....	1.47	4.56	1.12	1.18	2.56	4.63	0.52	1.67 ^b	2.21
Ferrous oxide (FeO).....	3.81	1.33	4.93	6.69	5.18	2.62	4.88	3.23 ^b	4.08
Lime (CaO).....	1.43	2.25	1.20	0.49	0.33	0.60	1.27	4.23	1.47
Magnesia (MgO).....	4.57	4.57	2.98	2.36	2.33	2.99	3.23	2.84	3.23
Potassa (K ₂ O).....	2.82	3.95	4.06	3.78	4.09	5.27	3.77	3.51	3.90
Soda (Na ₂ O).....	0.77	0.50	1.22	1.71	1.57	1.38	1.35	1.30	1.22
Carbon dioxide (CO ₂).....	1.89	3.15	1.41	0.30	0.08	0.54	1.40	3.67	1.55
Pyrite (FeS ₂).....	0.04	0.02	0.11	0.14	0.16	0.04	1.18	1.72	0.42
Water above 110°C (H ₂ O)...	3.21	2.82	3.27	4.01	3.81	3.16	3.82	4.09	3.53
Carbon (C).....			Trace				0.46	0.59	
Sundry others and water present below 110°C.....	0.66	0.77	0.69	0.51	0.39	0.56	0.70	1.11	0.67
Total.....	100.08	100.13	100.01	100.05	100.12	100.09	100.05	100.39	
Specific gravity†.....	2.717	2.796	2.776	2.795	2.805	2.806	2.774	2.783	2.783

* Figures in parentheses indicate the number of analyses averaged.

† Approximate.

Eureka quarry, Slatington, Calif.), but these modes of origin are of too rare occurrence to be considered here.

Clays, together with minor amounts of quartz, mica, zircon, carbonaceous matter, carbonates of calcium, magnesium, and iron, feldspar and other silicates in a fine state of subdivision, were slowly precipitated from suspension in water in successive beds differing somewhat in composition. These beds were later buried by a great depth of other sediments, the weight of which imposed sufficient pressure to consolidate the clay beds, forming shale. These beds of shale were then subjected to high temperature and intense pressure, crumpling and folding the beds and recrystallizing and changing the original minerals into new minerals, such as sericite, chlorite, quartz, and so on. Moreover, the intense pressure caused the new minerals to crystallize in parallel positions with their long axis

roughly perpendicular to the direction of the pressure. This parallelism of grains is the cause of the slaty cleavage.

The intensities of pressure and temperature vary considerably in different deposits, and hence the degree of metamorphism. Therefore there are complete gradations from unmetamorphosed shale, through partly metamorphosed shales (called clay slates), to highly altered "shales" or true slates. As the metamorphism increases in intensity, more clay and other minerals are changed to mica and the result is mica slates. With still further alteration the mica slates develop schistosity, forming phyllite and finally mica schists.

Mica slates are more resistant to absorption and are stronger than clay slates. They are therefore more desirable and form the chief slates of commerce.

Physical Properties. The most important properties of commercial slate are cleavability, color, permanence of color, hardness, strength, density, porosity, electrical resistance, and freedom from impurities or color bands that detract from the strength, permanence, or appearance of the slate. Many of these properties are discussed elsewhere under Structure, Testing, and other headings, but a few important properties are noted here.

Color. The more common colors are various shades of gray, blue-gray, black, red, various shades of green, and variegated; purple is less common; yellowish-brown, brown, and buff colors are usually due to weathering of outcrops or to fading. Colors other than gray or bluish gray are due chiefly to the presence of carbonaceous material (black) or of iron compounds. The market value of a slate depends largely upon its color and on the permanence of the color. Some slates fade or discolor rapidly, while others retain their original colors for many years. Spots and irregular fading colors are very objectionable.

Luster, varies from dull to highly micaceous. **Specific gravity,** usually about 2.7 or 2.8. **Melting point,** varies with composition. Bowles* states that a ground slate tested as a ceramic glaze melted much below cone 9 (1310°C).

Other Properties. Dale† gives the results of physical tests made on numerous slates, but, unfortunately, some of the values given are not in terms used in present-day standard tests. Bowles‡ quotes tests made at Lehigh University on electrical slate from the soft-vein slate belt of Pennsylvania.

Structure and Imperfections in Slate.§ **Bedding.** Because of changes in the character of the sediments during deposition, the slate beds may vary in color, chemical composition, and physical properties. The original beds have been compressed and metamorphosed to form slate, but the original inherent differences in the beds are preserved in differences of color, texture, and physical properties. The original shaly cleavage parallel to the bedding planes is replaced by a slaty cleavage that is independent of the plane of bedding. Bands or beds of darker color are known to quarry men as "ribbons."

Usually not all beds in a slate deposit are of commercial value, and the best beds, traceable by ribbons or other features, must be followed in quarrying.

* BOWLES, OLIVER, *The Technology of Slate*, U.S. Bur. Mines, Bull. 218, 1922, p. 101.

† DALE, T. N., *et al.*, *Slate in the United States*, U.S. Geol. Survey, Bull. 586, 1914, pp. 181-189.

‡ BOWLES, OLIVER, *op. cit.*, p. 7.

§ See Oliver Bowles, *op. cit.*, pp. 8-14; also T. N. Dale, *et al.*, *op. cit.*, pp. 27-49.

Thus the widths, dips, and changes in dip of the beds are important factors in the development and operation of a quarry.

Slaty Cleavage. Slaty cleavage is the most characteristic and, commercially, the most important slate structure. A good slate may be split in one direction into flat sheets, with smooth to fairly smooth surfaces, as thin as $\frac{1}{32}$ in. or even thinner. Uniform smooth slabs, 4 by 6 ft or even larger, are commonly split to a thickness of $\frac{3}{8}$ in. in making blackboards. This cleavage varies in perfection in different slates and is usually less perfect in weathered or dried slates.

Grain. In many slates there is a second, but far less pronounced, direction of splitting. This direction is known as the "grain." It is usually at approximately right angles to the slaty cleavage and usually follows a direction nearly at right angles to the strike of the slaty cleavage.

Curved Cleavage. Curved cleavage sometimes occurs, and, while it has been used to a limited extent as a source of curved slates for special purposes, it is to be regarded as an undesirable imperfection.

Slip cleavage or false cleavage is the property, occurring in certain zones of some slate deposits, that causes the slate to tend to part along parallel incipient joints, although there is usually no actual fracturing of the mass. It is a serious defect and may even cause the abandonment of a quarry.

Shear zones are sharp folds or series of folds due to shearing pressure on somewhat rigid material. They often intersect cleavage planes diagonally, producing angular blocks, and thus resulting in waste. Usually they are of minor importance.

Ribbons, as noted previously, are narrow bands representing original bedding planes and differing from the main body of the slate in color, texture, and composition. If they contain no injurious impurities or are not conspicuous, they may not be objectionable. They may be high in carbonates or other impurities, however, so that they weather more rapidly than the rest of the slate; or the ribbons may be so conspicuous as to be undesirable for many purposes.

Faults, or dislocations along fractures, are usually of little importance in slate quarries.

Veins of quartz (called "flints" by quarrymen) or calcite ("spar") or mixtures of quartz, calcite, dolomite, and perhaps chlorite and biotite are common in slate quarries. They occur at all angles and may be very irregular; they constitute objectionable imperfections.

Dikes, or intrusions of igneous rocks, usually parallel to joints, are common in slate deposits, but less common than veins. They are objectionable in that they cause waste and are planes of weakness that may cause rock slides.

Nodules. In some slates lenslike nodules of quartz, calcite, pyrite, and muscovite are found along bedding planes. They are objectionable defects, but quartz nodules are called "purifiers" by quarrymen, for they claim that the slate surrounding such nodules is unusually pure and uniform.

Other Impurities. In addition to the imperfections and impurities noted above, slates may contain pyrite, marcasite, carbon, and the carbonates more or less disseminated throughout certain portions or segregated in certain areas. Marcasite or mixtures of marcasite and pyrite decompose with comparative rapidity

SLATE

and form spots and stains of iron oxide. Pure crystalline pyrite, however, is fairly stable. Carbonates are objectionable, for they decompose rapidly, iron carbonate being particularly detrimental, for it both decomposes and stains.

Production and Consumption. The production of slate is shown in Table 2. Roofing slates are overlapped like shingles and a "square" of slate is the amount that will cover 100 sq ft of exposed roof. Table 2 exhibits the production of slate in the United States in recent years.

TABLE 2. SLATE SOLD BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948
Dimension Slate

Year	Roofing			Mill stock		Other*		Total	
	Squares	Approx equivalent short tons	Value	Approx short tons	Value	Approx short tons	Value	Approx short tons	Value
1944	89,090	32,750	\$ 802,179	12,440	\$ 715,689	15,760	\$203,090	60,950	\$1,720,958
1945	101,300	38,240	976,122	11,520	742,345	19,900	253,273	69,660	1,971,740
1946	146,790	56,240	1,982,928	12,150	1,032,584	27,860	403,990	96,250	3,419,502
1947	170,590	64,350	3,094,780	13,550	1,444,835	34,610	537,705	112,510	5,077,320
1948	218,650	82,090	4,566,056	11,950	1,600,019	46,490	700,477	140,530	6,866,552

Crushed Slate (Granules and Flour)

Year	Granules		Flour		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944	309,170	\$2,861,014	107,720	\$422,223	416,890	\$3,283,237
1945	374,800	3,299,593	107,430	387,580	482,230	3,687,173
1946	513,780	4,851,314	149,740	573,290	663,520	5,424,604
1947	593,560	5,911,151	169,940	697,083	763,500	6,608,234
1948	499,440	5,306,568	159,430	707,809	658,870	6,014,377

* Includes flagstones, walkways, stepping stones, and miscellaneous slate.

Production by states and its value are shown in Table 3. Note that production is limited to a few states and that among them Pennsylvania is the most important. Dimension stock is produced in Lehigh and Northampton counties. The Peach Bottom district in York and Lancaster counties, and extending into Maryland, of late years has produced only granules. All slate is of a typical gray color. The New York-Vermont area has the advantage of containing beds of slate of red, green, purple, and mixed colors. Imports usually are small in value and rarely exceed a few thousand dollars annually in value. Exports with a value from one-quarter to one-half million dollars have been recorded from 1942 to 1947. Most of the material exported consisted of granules and flour.

Slate is produced in a number of foreign countries, the most significant being Wales, a producer for centuries and the principal source for Great Britain.

TABLE 3. SLATE SOLD BY PRODUCERS IN THE UNITED STATES IN 1946, BY STATES AND USES

State	Operators	Roofing		Mill stock		Other uses (value)*	Total value
		Squares (100 sq ft)	Value	Square feet	Value		
Arkansas.....	1	.....	.....	.....	.....	†	†
California.....	1	.....	.....	.....	.....	†	†
Georgia.....	1	.....	.....	.....	.....	†	†
Maryland.....	1	.....	.....	.....	.....	†	†
New York.....	13	.....	.....	.....	.....	\$1,160,434	\$1,160,404
Pennsylvania.....	20	113,490	\$1,410,427	2,010,650	\$ 662,045	1,134,273	3,197,745
Vermont and Maine...	19	20,010	348,161	361,170	370,539	2,171,093	2,889,793
Virginia.....	5	13,290	233,340	.....	.....	†	†
Undistributed.....	..	.....	.....	.....	.....	1,362,824	1,596,164
Total, 1946.....	61	146,790	1,982,928	2,371,820	1,032,584	5,828,594	8,844,106
Total, 1945.....	46	101,300	976,122	2,107,780	742,345	3,940,446	5,658,913

* Flagging and similar products, granules, and flour.

† Included under "Undistributed."

Quarrying and Mining. Slate is mined underground in Wales and France and has been procured by this technique in Maine and Pennsylvania. The bulk of domestic slate is now obtained by quarrying. Since the beds of commercial material may stand at a high angle, up to 90 deg, quarries have been developed with vertical walls to great depth, such as are found in the Lehigh district in Pennsylvania. The problem of disposal of overburden and noncommercial rock may be serious, and the storage of such material in areas containing good rock may complicate the operation and render future use impossible. Common quarrying practice in the past consisted of the use of channeling machines for the freeing of blocks of slate from the quarry mass. Advantage was taken as much as possible of all natural partings, such as joints, loose ribbons, loose veins, and cleavage. Blocks were freed on four sides to permit removal. Holes in proper alignment were frequently drilled and wedged with the use of plugs and feathers. These methods had the disadvantages of high costs, the production of blocks of slate with rough edges requiring further treatment, and the loss of large tonnages of acceptable material by the "stunning" or shattering of rock adjacent to the channel cut. It has been estimated that while these methods were in common use 70 to 90 per cent of quarry output was rejected as waste.

The introduction of the wire saw in 1926 revolutionized the quarrying of slate. This equipment had been in use in Europe but was not applied in the United States until this recent date. It consists essentially of a power-driven loop of three-ply steel cable fed with a mixture of sand and water. The sand supplies the teeth of the saw and abrades the slate with ease as it is pulled across the face of the rock by the rapidly moving cable. The saw produces a smooth, narrow

cut with minimum waste. Since there is no shattering of the adjacent slate the percentage of waste connected with quarrying operations has been reduced substantially. The smooth blocks of slate may be split with little or no waste. It has been estimated that during the first year of its use this saw saved a quarter of a million dollars.

Utilization of Slate. The utilization of slate is based on its one most conspicuous property: it can be split readily into thin, flat flakes or slabs. These may be ground to a plane surface, suitable for billiard tables, blackboards, and similar uses. The rejects may be crushed and sized for granules of finely ground material for use as a filler. Distribution by use is shown in Table 4.

Economics of the Industry. Slate has encountered increasing competition in its major markets. Through hundreds of years slate has proved a superior roofing material, but in the past 30 years the asphalt shingle has become the most widely used roofing on the common home. The asphalt shingle can be applied with common labor; it comes in attractive colors; it has high fire resistance and is reasonably permanent. To some extent this loss has been compensated by the use of slate granules for surfacing the asphalt shingle. Pennsylvania is at a disadvantage in this market since its slate is available only in its natural slate color. The red, green, and purple slates of New York and Vermont supply a colorful granule in wide use. The artificially colored granule, essentially a ceramic product, is available in a wide range of colors and has been marketed in hundreds of thousands of tons, capturing a substantial portion of the market from slate and possessing such advantages as to retain it. The white "blackboard," a sheet of white or light-green glass with a ground surface, has displaced slate partially in the public-school market. Slate is basically a construction material, and during periods of activity in building such as may be expected to endure for several years after 1948 it is probable that it will enjoy an improved market.

One of the most pressing problems in the slate industry is the disposal of the large tonnages of waste material accumulated over years of quarry operation. Such waste is available in hundreds of thousands of tons. It possesses the advantage that no further expense need be encountered in extraction. It has been broken from the rock, removed from the quarry, and lies ready for conversion to useful form. This problem has been the subject of extensive research.⁹ As noted in the first part of this discussion, the mineral composition and chemical analysis of slate do not present any particular minerals or elements that are not available elsewhere more economically. The physical properties of ease of splitting, strength, fire resistance, dielectric strength, and color have been exploited to their commercial limits. Research has demonstrated that a number of new products may be manufactured from waste slate. Lightweight aggregate is one of the most promising. The use of lightweight aggregate in concrete is growing steadily. It was found that Pennsylvania slates contain enough carbonates and carbon to bloat upon heating without the addition of any extraneous materials. Pilot-plant operations in a rotary kiln employing temperatures of up to 2300°F turned out an aggregate weighing from 32 to 39 lb per cu ft. This compares with gravel at approximately 100 lb per cu ft and sand at 105 lb. The

TABLE 4. SALIENT STATISTICS OF THE SLATE INDUSTRY IN THE UNITED STATES, 1945 TO 1946

	1945			1946		
	Quantity		Value	Quantity		Value
	Unit of measure-ment	Approx equivalent short tons		Unit of measure-ment	Approx equivalent short tons	
Domestic production (sales by producers):	Squares			Squares		
Roofing slate.....	101,300	38,240	\$ 976,122	146,790	56,240	\$1,982,928
Mill stock:	Sq ft			Sq ft		
Electrical slate.....	363,210	3,100	\$ 283,650	389,210	2,760	\$ 366,039
Structural and sanitary slate.....	314,200	2,480	135,671	448,520	3,530	222,675
Grave vaults and covers.....	314,710	2,850	88,146	145,910	1,330	58,671
Blackboards and bulletin boards.....	649,510	1,650	170,392	808,710	2,090	240,520
Billiard-table tops.....	158,580	1,160	56,453	292,740	2,180	135,217
School slates.....	307,570*	280	8,033	286,730*	260	9,462
Total mill stock.....	2,107,780	11,520	\$ 742,345	2,371,820	12,150	\$1,032,584
Flagstones, etc†.....	2,995,670	19,900	253,273	4,322,220	27,860	403,990
Total slate as dimension stone.....	.....	69,660	1,971,740	.....	96,250	3,419,502
Granules and flour.....	.....	482,230	3,687,173	.....	663,520	5,424,604
Grand total domestic production.....	.....	551,890	\$5,658,913	.....	759,770	\$8,844,106

* Sq ft approximate. Number of pieces: 1945, 353,400; 1946, 535,950.

† Includes slate used for walkways, stepping stones, and miscellaneous uses.

working properties of the aggregate may be improved by pelletizing before calcination. It has been suggested that small pellets after bloating would be suitable for use in the increasing field of home insulation. It was proved also that slate could be used in the manufacture of mineral wool, improved ganules, and slate-lime brick. Slate contains sufficient quartz in a fine state of subdivision so that it bonds well when treated with lime and steam as described in the process mentioned in Sand-lime Brick. Waste may be finely ground and the powder bonded with suitable plastics and pressed into sheets for use as a blackboard or in similar capacity. Blocks of waste may be sawed into tiles or bricks. The fact that immense tonnages of waste slate are present in densely populated areas near New York and Philadelphia lends interest to the research efforts to discover industrial use for this material.

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SOAPSTONE*

Composition and Physical Properties. Properly speaking, soapstone is a massive rock the chief mineral component of which is talc, usually present in sufficient quantity to give the rock a soapy feel. The term "soapstone" is sometimes incorrectly applied to massive talc. The composition of soapstone is exceedingly variable and its talc content may be as low as 50 per cent. In fact, many soft, easily cut rocks in which chlorite predominates over talc are loosely called soapstone. Ordinarily, a soapstone of good quality contains, in addition

* See also Talc.

to talc, varying amounts of chlorite, tremolite, pyroxene, magnetite, quartz, calcite, and dolomite. *Melting point*, 1350 to 1400°C.

ANALYSES OF SOAPSTONE

	1	2	3	4
SiO ₂	46.15	39.06	51.20	63.5
Al ₂ O ₃	8.12	12.84	5.22	
Fe ₂ O ₃	2.04			
FeO.....	6.62	12.93	8.45	
MgO.....	28.73	22.76	26.79	31.7
CaO.....	Trace	5.98	1.17	
Na ₂ O.....	0.45			
K ₂ O.....	1.75			
H ₂ O ⁻	0.08			
H ₂ O ⁺	5.20	6.56	6.90	4.8
TiO ₂	0.10			
P ₂ O ₅	0.24			
S.....	Trace			
MnO.....	Trace			
Total.....	99.48	100.13	100.05	100.0

1. Chloritic soapstone, Calhoun estate, 15 miles east of Elberton, Ga. Asbestos, Talc and Soapstone Deposits of Georgia. *Georgia Geol. Survey, Bull.* 29, p. 192, Oliver B. Hopkins, authority.

2. Soapstone, Albermarle County, Va. *Proc. U.S. Natl. Museum*, p. 287, 1895.

3. Soapstone, Grafton, Vt. *U.S. Natl. Museum, Annual Report*, 1899, p. 316, G. P. Merrill, authority.

4. Theoretical composition of pure talc.

Soapstone is greenish gray in color. It is characterized by its soapy feel, the ease with which it may be sawed into slabs or structural shapes, high electrical resistance, resistance to heat and to acids, and slow radiation of heat.

Occurrence. Soapstone is usually derived from the alteration of a basic, igneous rock such as pyroxenite. Diller says:

The long narrow belts which it forms approximately parallel to the general trend of the neighboring rocks may suggest derivation by alteration from sedimentary rocks, but it is believed more probable that such rocks are intrusive and that the rock bodies are dikes rather than strata.

Where the alteration is complete and the pyroxene has changed to talc, the soapstone is softest, most easily worked, and best for certain purposes. Remnants of unaltered pyroxene render the rock harder and susceptible of a degree of polish that gives it a more attractive appearance. The pyroxene remnants may be partly soluble in acid, and the soapstone from such quarries is not desirable for purposes in which acids are employed.²

Soapstone of commercial value does not seem to be widely distributed, although its relatively limited use may be responsible for more deposits not being explored and reported. The confusion that exists in the use of the terms "soapstone," "steatite," and "talc" makes it difficult to interpret correctly the reported

occurrence of soapstone, particularly in foreign countries. It seems certain, however, that soapstone has been quarried for centuries by natives of India, China, Brazil, and other foreign countries for the manufacture of crude utensils such as bowls and pots. In the United States, Indians used to quarry soapstone and from it fashion various utensils. In later years deposits have been worked in many states to obtain soapstone for local use for foot warmers, fireplace lining, etc.

In the United States production has come chiefly from Virginia, but Washington is also a producer and, at times, one or two other states, such as California. Former small producers were Vermont, Maryland, North Carolina, Rhode Island, and New Hampshire. Maryland's recent production of steatite-type material and low-grade ground soapstone may perhaps more properly be classified under Talc.

The principal deposits in Virginia occur in a belt over 200 miles long extending across Nelson, Albemarle, and Orange counties, though deposits have been worked to some extent in many other counties, notably Fairfax, Franklin, Amelia, and Henry. By far the largest operations are and have been those of the Alberene Stone Corp. at Schuyler, Nelson County. Spence describes the Virginia soapstone as follows:

The Virginia soapstone is a medium- to fine-grained, gray-green rock, sometimes showing schistose structure or grain, and it is this schistose type that is best adapted for manufacturing. Three degrees of hardness are recognized, classified respectively as "soft stone," "tough stone," and "hard stone." The first contains the most talc and is the preferred type. Mineral constituents of the rock include talc, 5 to 85 per cent; chlorite, 5 to 50 per cent; serpentine, trace to 25 per cent; amphibole, trace to 50 per cent; carbonates, trace to 25 per cent; magnetite, trace to 25 per cent; pyrite, trace to 2 per cent. The "hard" stone contains the most chlorite and amphibole and the least talc, with the proportions reversed in the "soft" stone, and intermediate in the "tough" stone. The stone occurs in irregular lenses along the margins of the original basic rocks, with similar strike and dip to the latter. The lenses attain very large size, as in the Schuyler and Alberene quarries, where the soapstone bodies range up to 300 ft in width, with lengths of 1,200 and 2,000 ft, respectively.⁷

In Washington deposits of massive soapstone are worked in Skagit County, chiefly near Marblemount and Rockport. The operations at Rockport are the largest in the state. Here cut furnace stone for refractory-kiln lining and for kraft paper mills is the chief product, but some slab stone for architectural and other uses is produced, as well as talc crayons. The deposit, consisting of six beds or ledges exposed on a mountainside, is opened by an adit tunnel and mined by special underground methods. Rooms are first outlined by a coal cutting machine; then blocks, 8 ft long by 18 in. square, are cut out by a 40-in. circular saw with carborundum teeth. These blocks are then trammed and lowered to the mill 100 ft below the adit entrance.

In Vermont, quarries have been worked at Chester and Perkinsville; in Maryland, near Marriotsville, Carroll County, and near Dublin, Harford County, but deposits are also reported in Cecil and Montgomery counties; in North Carolina, in Alleghany County; in Rhode Island at Manville in Providence County; in

Georgia, in Elbert, Stephens, and Lumpkin counties; in California, near Shingle, El Dorado County.

In Canada practically all the production comes from the Eastern Townships in Quebec, mainly from the Thetford Mines area. The principal producer operates quarries and a mill near Leeds station in Broughton Township. The chief products are sawed blocks and bricks for kraft-paper-mill furnace linings, but some crayons and ground soapstone are produced. A large deposit of soapstone of excellent quality occurs in the Lake of the Woods region 1 mile west of Wabigoon station on the Canadian Pacific Railroad near Dryden, Ontario, but attempts to exploit it commercially have so far been unsuccessful.

In other countries massive soapstone production is noted in Norway, Sweden, Finland, Russia, Switzerland, and India, for use largely as local building stone, but to some extent, as in the Scandinavian countries, for kraft-paper furnace linings. A large part of the world demand for slab soapstone has been met by exports from the United States.

Production. Separate statistics of soapstone production for the United States have not been published since 1924, when production of 25,630 tons valued at \$1,288,885 was reported. In the decade before 1924 production ranged from 15,000 to 26,000 tons, valued at from about \$490,000 to \$740,000. No satisfactory figures for world production are available, due in part to poor collection of statistics and in part to confusion in terms between talc, soapstone, and pyrophyllite. A very large part of both United States and world production of slab soapstone comes from one producer in Virginia.

Mining and Milling. With one exception soapstone deposits worked for slab soapstone are operated by open-quarrying methods. A few small companies remove the stone from the ground by drilling and blasting, but, since the method tends to shatter the rock and destroy many good blocks, its use has been abandoned by large and progressive producers.

The aim of soapstone quarrying is to produce large, sound, rectangular blocks with a minimum of waste. The problems are almost identical to those of marble quarrying, except that soapstone is usually softer than marble and that no account need be taken of the figures or patterns which add to the value of polished marble. The methods of quarrying, handling, sawing, dressing, rubbing, and polishing soapstone, therefore, follow very closely those described in a publication of the U.S. Bureau of Mines (*Bulletin* 106, 1916) entitled "The Technology of Marble Quarrying," by Oliver Bowles and will not be repeated here in detail.

The most important soapstone deposits of Virginia, those of the Nelson-Albermarle County belt, occur as separate parallel beds, 30 to 165 ft in thickness and spaced up to 800 ft apart. The dip varies in conformity with the enclosing rocks, but at one point is about 60 deg. The total thickness of the beds is rarely minable due to imperfections in the stone, the minable thickness varying from 50 to 85 per cent of the total thickness. Few seams are encountered, and the joint planes are sufficiently far apart so that large blocks are easily obtainable.

The principal quarries are worked on a large scale, and the openings closely resemble marble quarries. Large blocks are cut out by channeling machines, hoisted to the surface, and loaded on cars for transportation to the mill.

It is reported that 80 to 90 per cent of the soapstone removed is waste, partly on account of pyrite, which may become oxidized and discolor the stone; partly on account of hard spots, which make sawing difficult; but chiefly because of small cracks that may cause the slabs to break. In the milling operations additional waste is made. Soapstone waste has not generally been utilized except in a limited way.

At the mills there are large storage yards for block stone, provided with traveling cranes for handling the blocks. In the mills the blocks are sawed into thin slabs by gang saws and the slabs are dressed, rubbed, and polished by typical marble-working machinery. Some soapstone is sold in blocks or in rough slabs, but most of it is fabricated at the mills into laundry tubs, laboratory hoods and tables, switchboards, etc.

Utilization. In the past soapstone has been used extensively for pots and kettles, stoves, fireplace linings, and foot warmers; as a building stone; and for firebrick. A few of these uses still persist to a certain extent, especially among primitive peoples, as in India. As a refractory, the resistance of soapstone to both high heat and chemical attack has made it an essential material with no known substitute for the lining of some types of alkali recovery furnaces in kraft pulp mills.^{1,6}

The principal uses for soapstone today, from both tonnage and value standpoints, are for slab soapstone. Relatively thin (1 to 2 in.) slabs, sawn from large blocks, are fabricated into laboratory sinks, hoods, and tabletops, acid-resisting tanks, kitchen sinks, laundry tubs, lavatories, structural units, electrical switchboards, griddles, heating stones for fireless cookers, and cores for electrical heating elements such as electric flatirons.

Ground soapstone is used to some extent in foundry facings, as a lubricant, as a dusting agent in making prepared roofing, in low-grade paints, and for a few other minor uses as a substitute for low-grade talc.

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* See also bibliography under Talc.

SODIUM COMPOUNDS

Sodium salts, in addition to sodium chloride or common salt, are produced and used in very large quantities, but most of them are manufactured from some other salt, chiefly sodium chloride, rather than mined in the natural state. Table 1 lists the chief sodium salts of commerce, giving both the common and the chemical names.

TABLE 1. NAMES AND FORMULAS OF SODIUM COMPOUNDS*

Trade name	Formula	Percentage	Chemical name
Soda ash.....	Na_2CO_3	98–100 Na_2CO_3	Sodium carbonate
Sodium sesquicarbonate, trona	$\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$	47 Na_2CO_3 ·37 NaHCO_3	Hydrated sodium carbonate-sodium bicarbonate
Sal soda, washing soda, crystal carbonate	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	37.1 Na_2CO_3	Hydrated sodium carbonate
Bicarbonate of soda, baking soda, saleratus	NaHCO_3	99.5–99.7 NaHCO_3	Sodium bicarbonate or acid sodium carbonate
Caustic soda.....	NaOH	75–99 NaOH	Sodium hydroxide
Soda lime.....	$\text{NaOH} + \text{CaO}$	.....	Sodium hydroxide and calcium oxide
Borax.....	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	52.7 $\text{Na}_2\text{B}_4\text{O}_7$	Sodium tetraborate
Tincal.....			
Sodium hyposulfite.....	$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$	64 $\text{Na}_2\text{S}_2\text{O}_3$	Sodium thiosulphate
"Hypo".....			
Yellow prussiate of soda..	$\text{Na}_4\text{Fe}(\text{CN})_6 \cdot 10\text{H}_2\text{O}$	62.7 $\text{Na}_4\text{Fe}(\text{CN})_6$	Sodium ferrocyanide
Red prussiate of soda.....	$\text{Na}_3\text{Fe}(\text{CN})_6 \cdot \text{H}_2\text{O}$	94 $\text{Na}_3\text{Fe}(\text{CN})_6$	Sodium ferricyanide
Sodium nitroprusside.....	$\text{Na}_2\text{Fe}(\text{CN})_5\text{NO} \cdot 2\text{H}_2\text{O}$	88 $\text{Na}_2\text{Fe}(\text{CN})_5\text{NO}$	Sodium nitroprusside
Salt cake.....	Na_2SO_4	98–100 Na_2SO_4	Sodium sulfate
Niter cake.....	NaHSO_4	61–86 NaHSO_4	Sodium bisulfate or sodium acid sulfate
Glauber's salt.....	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	44.1 Na_2SO_4	Hydrated sodium sulfate
Chile saltpeter.....	NaNO_3	95–96 NaNO_3	Sodium nitrate
Soda niter.....			
Water glass.....	$\text{Na}_2\text{O} \cdot 4\text{SiO}_2$ (approx)	.....	Sodium silicate
Sodium carbonate monohydrate	$\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$	85–86 Na_2CO_3	Sodium carbonate monohydrate

* WELLS, R. C., Sodium Compounds in 1919, *Mineral Resources of the United States*, Pt. 2, p. 55, U.S. Geol. Survey, 1919.

Many sodium compounds exist as minerals, often occurring in large quantities. Some of these minerals, such as halite or common salt and sodium nitrate, are mined in large quantities. Other minerals, such as natural sodium sulfates and carbonates, are mined in limited quantities, but at present these salts are manufactured chiefly from sodium chloride. All the natural sodium salts are more or less soluble in water and consequently cannot exist as solid substances at or near the earth's surface, except in very arid climates. In other localities, somewhat less arid, these salts exist as more or less saturated brines and bitterns in salt lakes and saline springs. In regions of moderate or excessive rainfall, no opportunity is afforded for natural, solar concentration of brines, and commercial deposits of sodium salts do not occur except in depth. Table 2 contains the names of the

SODIUM COMPOUNDS

more important natural sodium salts, together with a few of the less common salts.

Several of these minerals are treated elsewhere in this book, halite under Salt; natural sodium nitrate under Nitrates; borax and kernite under Borax and Borates. The following brief accounts of some of the more important minerals listed in Table 2 are somewhat abbreviated from descriptions by Gale.⁶

TABLE 2. NATURAL SODIUM SALTS

Mineral name	Formula	Relative solubility in water
Halite.....	NaCl	Very soluble
Mirabilite.....	Na ₂ SO ₄ ·10H ₂ O	Very soluble
Thenardite.....	Na ₂ SO ₄	Very soluble
Trona (urao).....	Na ₂ CO ₃ ·NaHCO ₃ ·2H ₂ O	Readily soluble
Natron.....	Na ₂ CO ₃ ·10H ₂ O	Very soluble
Burkeite.....	Na ₂ CO ₃ ·Na ₂ SO ₄	Slowly cold, readily hot
Kernite.....	Na ₂ B ₄ O ₇ ·4H ₂ O	Slowly cold, readily hot
Borax (tincal).....	Na ₂ B ₄ O ₇ ·10H ₂ O	Very soluble
Ulexite.....	NaCaB ₅ O ₉ ·8H ₂ O	Insoluble in cold water
Glauberite.....	Na ₂ SO ₄ ·CaSO ₄	Slightly soluble
Hanksite.....	9Na ₂ SO ₄ ·2Na ₂ CO ₃ ·KCl	Readily soluble
Northupite.....	Na ₂ CO ₃ ·NaCl·MgCO ₃	Slightly soluble
Pirssonite.....	Na ₂ CO ₃ ·CaCO ₃ ·2H ₂ O	Slightly soluble
Gaylussite.....	Na ₂ CO ₃ ·CaCO ₃ ·5H ₂ O	Slightly soluble
Sulfohalite.....	2Na ₂ SO ₄ ·NaCl·NaF	Slightly soluble
Tychite.....	2Na ₂ CO ₃ ·Na ₂ SO ₄ ·2MgCO ₃	Almost insoluble
Searlesite.....	Na ₂ O·B ₂ O ₃ ·4SiO ₂ ·2H ₂ O	Almost insoluble
Astrakanite.....	Na ₂ SO ₄ ·MgSO ₄ ·4H ₂ O	Readily soluble
Glaserite.....	NaKSO ₄ or K ₃ Na(SO ₄) ₂ (K ₂ SO ₄ = 78.6 — 61.8 per cent)	Fairly soluble

Mirabilite (Glauber Salt). Decahydrated sodium sulfate, or mirabilite, Na₂SO₄·10H₂O [sulfur trioxide (SO₃), 24.8 per cent; soda (Na₂O), 19.3 per cent; water (H₂O), 55.9 per cent], is a colorless, transparent crystalline salt, which separates from its solutions by evaporation in the open air or by chilling of its saturated solutions below 33°C, the separation being accompanied by evolution of heat. It forms in large crystals, often needlelike, with the development of many faces in a long, prismatic form. Its hardness is 1.5 to 2 and its specific gravity, 1.5. It crystallizes in the monoclinic system. The crystals are readily efflorescent in dry air, losing their water and falling to a white powder. Its common occurrence in nature is therefore in standing saturated solutions or mixed in other salts. It is very soluble in water and its solubility increases markedly with a rise in temperature. At 0°C, 100 parts of water dissolve 5.02 parts sodium sulfate, while at 33°C, the point of its greatest solubility, the same quantity of water dissolves 50 parts sodium sulfate. *Taste*, cool, then feebly saline, with a bitter aftereffect.

Thenardite. Anhydrous sodium sulfate, or thenardite, Na_2SO_4 [soda (Na_2O), 43.68 per cent; sulphur trioxide (SO_3), 56.32 per cent], occurs in crystalline form or finely powdered as a result of dehydrating crystallized mirabilite. It forms clear transparent to brownish crystals, the color being due to included impurities. It crystallizes in the orthorhombic system in pointed pyramids, combined into crusts, with surface rough. The crystals are commonly twinned, as in some specimens from Searles Lake. In the air it becomes dull by absorbing water. Its specific gravity is 2.655. It results from the evaporation of solutions above 33°C or from strongly alkaline solutions, as by the addition of sodium carbonate, at ordinary temperatures. It is very soluble in water and has a faintly saline taste.

Trona. Trona, or urao, $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ [sodium carbonate (Na_2CO_3), 46.90 per cent; sodium bicarbonate (NaHCO_3), 37.17 per cent; water (H_2O), 15.93 per cent—or in the other form carbon dioxide (CO_2), 38.9 per cent; soda (Na_2O), 41.2 per cent; water (H_2O), 19.9 per cent], is undoubtedly the most important of the natural soda minerals and constitutes the greater part of most natural soda deposits. It occurs as beds of white cavernous material with acicular or bladed crystals lining the cavities, commonly intermixed with more or less earthy material and other salts. It is a glassy or translucent salt, white or stained by impurities. It crystallizes in the monoclinic system, fibrous or columnar massive. It has one perfect cleavage. Its hardness is 2.5 to 3 and its specific gravity about 2.15 in specimens of naturally deposited crystals from Owens Lake examined by Chatard.² It appears to be permanent in dry air, is very soluble in water and effervesces with acids. Its taste is alkaline.

This mineral was shown by Chatard to be among the first of the more soluble constituents to crystallize on concentration of such saline solutions as the waters of Owens and Mono lakes. In the lower part of the main deposit at Searles Lake it occurs as a yellowish caked granular mass, always saturated with the dense mother-liquor brine.

Natron. Decahydrated sodium carbonate, or natron, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ [soda (Na_2O), 21.69 per cent; carbon dioxide (CO_2), 15.37 per cent; water (H_2O), 62.94 per cent], is the ordinary crystal soda of commerce. It forms transparent colorless crystals, as clear as water, of the monoclinic system. It has one good cleavage and another less perfect. According to Thorpe,* it crystallizes only at temperatures below 20°C , and thus only under exceptional conditions is it likely to be found in the soda lakes of desert regions; and, if formed and exposed, it would soon effloresce into the monohydrate ($\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$) known as *thermonatrite*. It liquefies at 34°C † in its water of crystallization, secreting monohydrated salt and leaving a liquid portion containing over 10 molecules of water, and again solidifying when the temperature is reduced to $33\frac{1}{2}^\circ\text{C}$. It effloresces quickly in the air and so does not naturally occur in crystal form except as immersed in saturated solutions. Its specific gravity has been variously determined as 1.423 to 1.475. Its taste is strongly alkaline.

As stated by Chatard, sodium carbonate is most soluble in pure water at 32.5°C ,

* THORPE, E., "A Dictionary of Applied Chemistry," Vol. 3, p. 662, 1912.

† LUNGE, GEORGE, "Sulphuric Acid and Alkali," Vol. 2, Pt. 1, p. 47, 1909.

the solution then containing 59 parts sodium carbonate to 100 parts water. Hence a solution that has deposited crystals at the boiling point redissolves them while cooling till the temperature sinks below 32.5°C, when recrystallization begins. The solubility varies greatly with the temperature. Thus, at 15.5°C the saturated solution contains 14.53 per cent; at 31.3°C, 30.04 per cent; and at 32°C, 31.78 per cent.

Borax. Borax, the sodium tetraborate, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ [boron trioxide (B_2O_3), 36.6 per cent; soda (Na_2O), 16.2 per cent; water (H_2O), 47.2 per cent], occurs in crystalline form in the Searles Lake deposits, having been extensively worked from the saline crusts in the marshy deposits about the margins of the flat. Borax or some similar compound of boron is also one of the more important constituents of the brine. It has been obtained in drilling as isolated and completely terminated crystals, some of them associated with the crystallized hanksite. It forms in large transparent monoclinic prisms, with truncated lateral edges. The crystals effloresce to an opaque white on the surface when brought into the air, but retain their form. Borax crystallizes in the monoclinic system. It has one perfect cleavage and others less distinct, is rather brittle, and has conchoidal fracture. Its hardness is 2 to 2.5 and its specific gravity 1.7. It is soluble in water, especially in hot water, which dissolves double its weight of the salt. It has a sweetish, cooling, alkaline taste.

Borax forms artificially two varieties of crystals: (1) ordinary or prismatic borax, the decahydrate that is produced by allowing solutions of borax to crystallize by cooling down to the ordinary temperature; and (2) octahedral borax, a pentahydrate that separates when a solution crystallizes above 50°C.

Glauberite. Glauberite, $\text{Na}_2\text{SO}_4 \cdot \text{CaSO}_4$ [sulfur trioxide (SO_3), 57.6 per cent; lime (CaO), 20.1 per cent; soda (Na_2O), 22.3 per cent], occurs commonly in playa mud deposits in the form of transparent colorless crystals, in thin rhomboids (of plowshare shape) ranging from $\frac{1}{2}$ to 1 in. or more in length. It also occurs in more or less massive aggregates of thin rhombic crystals intergrown. It crystallizes in the monoclinic system. It is brittle, with one perfect cleavage, and has a conchoidal fracture. Its hardness is 2.5 to 3; its specific gravity 2.7 to 2.85. It is soluble in hydrochloric acid. In water it loses its transparency and is partly dissolved, the crystal becoming coated with white calcium sulfate. It has a faintly saline taste.

Hanksite. Hanksite, $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$ [sodium sulfate (Na_2SO_4), 81.7 per cent; sodium carbonate (Na_2CO_3), 13.5 per cent; potassium chloride (KCl), 4.8 per cent], was first identified in 1885 by W. E. Hidden in collections from Searles Lake, where it is found in large amounts, chiefly in isolated crystals, commonly of quartzoid form, although found also in flattened tabloids.

The mineral is clear, transparent, and almost colorless, inclining to a more or less decided yellow, but often clouded by impurity. It crystallizes in the hexagonal system. It has one distinct cleavage and is brittle, with uneven fracture. Its hardness is 3 to 3.5; its specific gravity, 2.55. It is readily soluble in water, effervesces with acid, and has a strongly alkaline taste.

Northupite. Northupite, $\text{MgCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot \text{NaCl}$ [magnesium carbonate (MgCO_3), 33.9 per cent; sodium carbonate (Na_2CO_3), 42.6 per cent; sodium chloride

(NaCl), 23.5 per cent], has been found only among materials brought from the deep well at Searles Lake, where it was reported as occurring in a stratum of clay encountered at a depth of about 450 ft. It is colorless, transparent, or glassy when pure, but often clouded by impurities. It apparently suffers no decomposition on exposure to the air. Except for two crystals attached to pirssonite, northupite has been observed only in detached crystals. It crystallizes in the isometric system, the octahedron being the only form observed.

The crystals are small, being from less than 1 mm to nearly 1 cm in diameter. There is no apparent cleavage. The crystals are extremely brittle and show conchoidal fracture. Its hardness is 3.5 to 4; its specific gravity, 2.38. It is very slightly soluble in cold water, although rapidly decomposed by hot water, with separation of magnesium carbonate; and it is easily soluble and effervesces in dilute hydrochloric acid.

Pirssonite. Pirssonite, $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ [calcium carbonate (CaCO_3), 41.3 per cent; sodium carbonate (Na_2CO_3), 43.8 per cent; water (H_2O), 14.9 per cent], was first recognized among some crystals of gaylussite found in the deep well at Searles Lake, and has been reported only from that locality. With the exception of two crystals that were attached to northupite crystals, pirssonite was at first observed only in detached crystals. It has, however, been found among the well samples in fragment form, presumably having been pounded up by the drill, and also in a massive aggregate acting as a sort of cement in more or less consolidated muddy layers of the deposit. The mineral crystallizes in the orthorhombic system and is hemimorphic in its development. The crystals are colorless, transparent, or darkened by impurities. It is extremely brittle, having a conchoidal fracture with no apparent cleavage. Its hardness is 3 to 3.5 and its specific gravity 2.35.

Gaylussite. Gaylussite, a hydrous carbonate of calcium and sodium, $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 5\text{H}_2\text{O}$ [calcium carbonate (CaCO_3), 33 per cent; sodium carbonate (Na_2CO_3), 35.8 per cent; water (H_2O), 30.4 per cent], is a colorless transparent mineral occurring in small glassy crystals, many clouded by impurities, usually found embedded in mud or clay. It crystallizes in the monoclinic system. It has one perfect cleavage and a conchoidal fracture. Its hardness is 2 to 3; its specific gravity, 1.9 to 1.95. It is slightly soluble in water, the sodium carbonate going into solution and leaving a white coating of calcium carbonate on the crystal surface. It effervesces briskly with acids.

Sulfohalite. Sulfohalite, a sodium sulfate, chloride, and fluoride, $2\text{Na}_2\text{SO}_4 \cdot \text{NaCl} \cdot \text{NaF}$ [sodium sulfate (Na_2SO_4), 73.9 per cent; sodium chloride (NaCl), 15.2 per cent; sodium fluoride (NaF), 10.9 per cent], is a rare, transparent mineral having a faint greenish-yellow color and occurs in distinct crystals in association with hanksite at Searles Lake. The crystals are isometric, simple rhombic dodecahedrons, and octahedrons in form. The crystals vary in size from 0.5 to 2.5 cm in diameter. The specific gravity is 2.5 and the hardness about 3.5. The mineral is very slowly soluble in water and remains unaltered in a moderately dry atmosphere. The occurrence of fluorine is notable in the series of saline minerals deposited from concentrated lake waters, fluorine, like borax, being generally considered an index of fumarole or solfataric action.

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Tychite. Tychite, $2\text{MgCO}_3 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$ [magnesium carbonate (MgCO_3), 32.3 per cent; sodium carbonate (Na_2CO_3), 40.5 per cent; sodium sulfate (Na_2SO_4), 27.2 per cent], was discovered by the merest chance in 1895, when some northupite crystals from Searles Lake were being studied in the mineralogic laboratory of the Sheffield Scientific School at New Haven, Conn.

The individual crystals are transparent and colorless, effervesce readily with acid, and were distinguished from northupite by the fact that they gave no chloride test but a sulfate reaction instead. The composition was later determined from similar material prepared synthetically, which is supposed, however, to be the true mineral. Its specific gravity is about 2.45; its hardness, about 3.5

TABLE 3. UNITED STATES ANNUAL PRODUCTION, SHORT TONS

	1942	1943	1944	1946
Sodium carbonates:				
Natural ^a	150,619	165,993	184,826	215,625
Am-soda process.....	3,788,583	4,407,600	4,538,398	4,284,23
Total.....	3,939,202	4,573,593	4,723,224	4,499,856
Sodium sulfates:				
Natural ^b chemical products...	169,870	160,622	168,923	198,781
Crude ^c chemical products...	601,130	616,386	627,166	496,118
Refined ^d	71,784	76,608	69,997	122,573
Total.....	842,615	853,166	866,086	817,472
Imports:				
Crude ^e	93,661	32,790	31,305	22,446
Total.....	936,276	886,406	897,391	839,918

^a Soda ash, chiefly, but some trona and bicarbonate. For 1946, reduced to equivalent Na_2CO_3 .

^b Includes glauber salt converted to 100 per cent Na_2SO_4 basis.

^c Glauber salt and salt cake.

^d Anhydrous 100 per cent Na_2SO_4 .

^e Salt cake.

to 4. It is almost insoluble, even in hot water. It crystallizes in the isometric system in octahedrons. Only four natural crystals have ever been found.

Searlesite. Searlesite, a hydrous sodium borosilicate, $\text{Na}_2\text{O} \cdot \text{B}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, in spherulites of radiating fibers, was found embedded in the muds in the Searles deep well at a depth of 540 ft. It is colorless or white. It is soft, and its gravity has not been determined on account of lack of material. It is intimately associated with calcite and less intimately with pirssonite. It may prove of particular interest if found more abundant, since it contains theoretically about 17.15 per cent of boric acid.

Production and Consumption. The United States production of sodium carbonate and sodium sulfate for recent years is shown in Table 3, from statistics of the Bureau of Mines and the Bureau of the Census, in part recalculated.

In recent years (1946 to 1949) sodium carbonate has been produced in California (Searles Lake, two producers; and Owens Lake, one producer) and from the

trona deposit at Westvaco, Wyo. Sodium sulfate has been produced in these years in California (at Trona, Searles Lake, and near Amboy at Dale Lake); in Texas at Monahans, Brownfield, and O'Donnell; and in Wyoming from near Casper and near Rawlins.

Occurrence. Although natural sodium salts are known to occur in many localities in the world, often in large deposits, production has not been large, (except for common salt, the nitrates, and borates), until fairly recent years. This has been due chiefly to economic reasons. They are low-priced commodities, the principal deposits have been at considerable distances from important

TABLE 4. ANALYSES OF INCRUSTATIONS DEPOSITED FROM PLAYA LAKES IN CALIFORNIA, NEVADA, AND WYOMING

	1	2	3	4	5
Na ₂ CO ₃	72.69	75.95	45.05	44.25	30.62
NaHCO ₃.....	.....	.....	34.66	34.90	30.09
Na ₂ SO ₄	17.49	4.67	1.29	0.99	25.75
NaCl.....	2.53	1.46	1.61	1.10	2.13
NaNO ₃.....	.....	12.98			
NaH ₂ PO ₄.....	.....	4.94			
Na ₂ B ₄ O ₇	4.15				
KCl.....	1.18				
SiO ₂	1.96				
Insoluble.....	.....	.....	0.80	2.81	2.61
H ₂ O.....	.....	.....	16.19	15.95	9.01
	100.00	100.00	99.60	100.00	100.21

1. Soluble part from surface of playa, north arm of Old Walker Lake, Nev. *U.S. Geol. Survey, Bull.* 616, 1916, p. 237. T. M. Chatard, analyst.

2. From the Merced bottoms, Merced County, Calif. *Report*, Experiment Station, University of California, App., 1890. Analysis reported by E. W. Hilgard.

3. Big Soda Lake, Ragtown, Nev. *Fortieth Par. Report*, Vol. 2, p. 748, U.S. Geol. Exploration, 1877. O. D. Allen, analyst.

4. Little Soda Lake, Ragtown, Nev., *Idem*, p. 759.

5. Surface soda from Carbon County, Wyo. *Mineral Resources of the United States*, 1885, U.S. Geol. Survey, 1886, p. 553. Analysis reported by J. D. Weeks.

markets, and the salts could be made chemically or imported more cheaply than they could be mined and shipped long distances.

The chief and almost only sources of natural sodium carbonates and sulfates are (1) dry or nearly dry salt lakes in closed basins, called playas or playa lakes, in arid regions like Searles and Owens lakes, Calif.; (2) salt lakes such as Great Salt Lake, Utah; (3) deeply buried bedded deposits, as the trona bed at Westvaco, Wyo.; and (4) deep-seated natural brines as in Texas. Until the very recent development of the Wyoming trona the playa lake deposits have been by far the most productive sources. Table 4 gives the analyses of typical playa lake incrustations quoted by Wells.*

* WELLS, R. C., Sodium and Sodium Compounds, *Mineral Resources of the United States*, Pt. 2, pp. 176-178, U.S. Geol. Survey, 1918.

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TABLE 5. ANALYSES OF ALKALINE LAKE WATERS

	1	2	3	4	5	6	7
Cl.....	41.04	35.37	22.64	15.00	30.55	18.27	34.37
SO ₄	5.25	10.51	12.47	9.74	0.12	4.18	1.80
CO ₃	14.82	{ 7.79	19.76	19.58	20.42	35.57	{ 15.33
HCO ₃		{ 8.10	5.93	4.29	1.72		{ 9.03
Na.....	33.84	35.37	36.82	37.25	36.06	39.48	37.51
K.....	2.11	2.13	1.80	2.06	1.47	1.59	1.37
Ca.....	0.25	.....	0.04	.....	0.03	Trace	.....
Mg.....	2.28	0.21	0.10	.....	0.33	Trace	.....
SiO ₂	0.95	0.25	0.14	0.20	0.01	0.62	0.59
Al ₂ O ₃.....	.....	.....	Trace	.....	Trace	0.27	.....
B ₄ O ₇.....	.....	0.26	0.30	1.88	4.78	.....	.....
Fe ₂ O ₃.....	.....	.....	Trace	.....	.....	Trace	.....
Br.....	.....	.....	.....	.....	0.03	.....	.....
PO ₄.....	.....	.....	.....	.....	0.02	.....	.....
Organic.....	.....	.....	.....	.....	4.46	.....	.....
NO ₃.....	.....	.....	.....	.....	.....	0.02	.....
Salinity, ppm.....	100.00 3,486	100.00 113,700	100.00 51,170	100.00 118,830	100.00 76,560	100.00 16,633	100.00 39,172

1. Pyramid Lake, Nev. Mean of four concordant analyses by F. W. Clarke.

2. The large Soda Lake, Ragtown, Nev. *U.S. Geol. Survey, Bull.* 9, 1884, p. 25. Sample from a depth of 30.5 m. T. M. Chatard, analyst. An earlier analysis of Soda Lake by O. D. Allen is given in the *Fortieth Par. Report*, Vol. 2, p. 748, U.S. Geol. Exploration, 1877. It is less complete than Chatard's, but otherwise is not very different. Specific gravity, 1.101.

3. Mono Lake, Calif., *U.S. Geol. Survey, Bull.* 60, 1880, p. 53. Sample taken in 1882. Specific gravity, 1.045. T. M. Chatard, analyst. An improbable analysis of Mono Lake water, by Winslow Anderson, is given in his "Mineral Springs and Health Resorts of California," San Francisco, 1892, p. 198. In it the calcium salts predominate over all others.

4. Owens Lake, Calif. Analysis in the laboratory of the U.S. Geological Survey, 1913. Specific gravity, 1.0977. W. B. Hicks, analyst. An analysis by J. G. Smith is given in *U.S. Dept. Agr. Bull.* 61, 1914, p. 80.

5. Borax Lake, Calif. Analysis by W. H. Melville, published by G. F. Becker in *U.S. Geol. Survey, Mon.* 13, 1888, p. 265. In addition to the substances named in the table, the original residue contained 4.5 per cent of organic matter.

6. Summer Lake, Ore. Analysis by W. Van Winkle, who cites two other analyses. Specific gravity, 1.0162 at 15°C.

7. Albert Lake, Ore. *U.S. Geol. Survey Bull.* 60, 1890, p. 55. T. M. Chatard, analyst. An earlier analysis by F. W. Taylor is not in accord with this. Specific gravity, 1.03117 at 19.8°C.

The analyses of alkaline lake waters given in Table 5 are mostly selected from *Water Supply Paper* 364, U.S. Geological Survey.

Sodium Carbonates. *United States. California.* Playa lake deposits of alkaline salts are numerous in California in San Bernardino, Inyo, Mono, Lake, San Luis Obispo, Imperial, and Kern counties. King¹⁰ has made an excellent recent study of those deposits of greatest commercial value. Dub⁵ has described the operations at Owens Lake.

At Searles Lake there are two producers: the American Potash & Chemical

Corp. at Trona, which recovers sodium carbonate and sulfate, borax, bromine, and lithium-sodium phosphate; and the West End Chemical Co. at West End, which produces soda ash and borax. At Owens Lake there are three producers of soda ash. The process here is essentially as follows: partial concentration by solar evaporation in ponds; heating by steam to 100 to 110°F and carbonation with boiler flue gas, precipitating sodium sesquicarbonate (trona); settling and thickening; dewatering of sludge in centrifuges; and calcining to soda ash. The solution may be run to waste or used as feed in a borax recovery process. At Trona on Searles Lake the process is much more complicated because of the recovery of so many different products.

Owens Lake in southern Inyo County has an area of about 100 square miles, 5 to 9 ft deep in the deepest portions. It is a mixture of crystalline solids with 30 to 35 per cent brines containing up to 35 per cent anhydrous salts. At most seasons it is dry on the surface. From an analysis (see Table 5) made in 1913, Dub⁵ has calculated the tonnages of commercial salts in the lake at that time (see Table 6).

TABLE 6. OWENS LAKE RESERVES OF COMMERCIAL SALTS

	<i>Short Tons</i>
Salt (NaCl).....	64,000,000
Sodium sulfate (Na ₂ SO ₄).....	24,000,000
Sodium carbonate (Na ₂ CO ₃).....	58,400,000
Sodium borate (Na ₂ B ₄ O ₇).....	3,800,000
Potassium chloride (KCl).....	6,500,000
Silica (SiO ₂).....	340,000
Total.....	157,040,000

Searles Lake, in the Mojave Desert, San Bernardino County, has an area of about 12 square miles with a top layer of salts 60 to 90 ft thick. It is similar to Owens Lake but has a much higher salinity, higher potash content, and a wider range of commercial salts (see analysis under Potash). In 1948 the American Potash & Chemical Corp. at Trona recovered the following tonnages (annual report of the company):

	<i>Short Tons</i>
Potash.....	230,223
Borax.....	113,893
Soda ash.....	99,202
Salt cake.....	196,149
Miscellaneous*.....	1,601
Total.....	641,068

* Includes bromine and lithium compounds.

Brine has been pumped from wells in the salt body 60 to 70 ft deep, but in 1948 a new plant was completed to treat brines from lower level beds, higher in soda ash and borax and lower in potash than the upper beds. This plant will add 60,000 tons of soda ash per year and 30,000 tons of borax to previous production.

Wyoming may be potentially one of the largest producers of natural sodium carbonate in the country from the deposits of very pure trona²⁰ at Westvaco, 18 miles west of Green River. These deposits, crossed by the main line of the

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Union Pacific Railroad, were discovered at a depth of 1,500 to 1,600 ft while drilling for gas in 1938. Later drilling showed that the nearly horizontal beds vary in thickness from 8 to 14 ft or more over a very wide area and contain an estimated 158 million tons. In 1946 the Westvaco Chlorine Products Corp. acquired the deposits, sank a shaft, and built a refining plant reported to be for a capacity of about 60,000 tons per year. Not only is this becoming an important source of soda ash but also it may be instrumental in developing the large deposits of wyomingite, containing 11 per cent potash as leucite, less than 70 miles to the northeast. By a process developed by the U.S. Bureau of Mines wyomingite may be reacted with trona to produce soda ash and potassium carbonate as coproducts (see Potash).

Other localities in the United States that have produced soda ash commercially but are no longer active are

"Union Pacific Lakes," 13 miles south of Laramie, Wyo.	Owens Lake, Inyo County, Calif.
Downey Lakes, 18 miles southwest of Laramie, Wyo.	Grant County, Wash.
Soda Lakes, Ragtown, Nev.	Green River, Wyo.
Long Valley, southeast of Mono Lake, Calif.	Vernon, Calif.
	Dorris, Calif.
	Antioch, Neb.

Mexico. At Ecatepec de Morelos,²² 18 miles west of Mexico City, a new plant of the Sosa Texcoco, was started in 1948 to recover soda ash from the natural brines of Lake Texcoco. These brines contain 1 to 2 per cent salts, mainly sodium chloride, carbonate, and bicarbonate, and overlies solid deposits, 50 to 60 ft below the surface, reported to contain over 100 million tons. The brine is first concentrated by solar evaporation to about 20 per cent solids, the sodium carbonate further carbonated to the less soluble bicarbonate, separated from the salt mother liquor by thickening and centrifuging, dried, and calcined to commercial soda ash. Common salt may be recovered later. Part of the 100 ton per day soda-ash production will be used to make about 30 tons per day of caustic soda. It is estimated that this plant will supply about 30 per cent of Mexican requirements for these chemicals.

East Africa. At Kajrado, British East Africa, Lake Magadi, covering about 6 square miles, is said to contain at least 200 million tons of natural soda. This lake, which is on the borders of Tanganyiki Territory and Kenya Colony, is connected by a railway with the main line of the Uganda Railway at a point called Magadi Station, about 40 miles east of Nairobi. These deposits have been worked extensively both to supply local requirements and for export.

South Africa. In Pretoria, South Africa, natural soda is found in the Pretoria Salt Pan, near Hamaan's Kraal. This is a craterlike depression about 200 ft below the level of the surrounding country, covering about 28 acres.

Egypt. The natron lakes of Egypt are located in Wadi Natron, in Lower Egypt, southwest of the delta, in the desert of St. Macarius, about 60 miles northwest of Cairo and about 30 miles from the Nile.

Other deposits are in the *Province of Tripoli* near Fezzan.

Canada. There are a number of small shallow soda lakes in British Columbia north of Clinton that have occasionally produced very small tonnages of soda ash per year.

Other Countries. Alkaline lakes and other sources which yield sodium carbonate, but which are chiefly of local importance, have been noted in many other countries, some of which are listed below. Most of these are described either by Chatard or by Grabau or by both authorities.

Venezuela. In the valley La Lagunilla in the Province of Maracaibo, 48 miles from the city of Merida.

Chile and Peru. Arid plateau regions.

Armenia. Lakes of the Araxes Plain near Mt. Ararat.

Hungary. Many deposits, but that near Szegedin is the most important.

Germany. Waters of the Laacher See; of low salinity.

India. A number of deposits, but particularly in Burma, near Moulmein.

Sodium Sulfate. *United States.* There are important deposits of sodium sulfate in most of the western states, including Arizona, California, Colorado, Idaho, Nevada, New Mexico, North Dakota, Oregon, Texas, Utah, Washington, and Wyoming. In recent years production has come largely from California, with minor production from Texas and Wyoming.

California. In addition to the important production at Trona, Searles Lake, sodium sulfate is also produced at Dale Lake near Twentynine Palms. Some years ago production also came from Soda Lake, in Carrizo Plain, southwest of McKittrick, San Luis Obispo County. King¹⁰ lists five other deposits that he considers most promising for commercial development.

Arizona. The U.S. Tariff Commission states²¹ that the largest deposits of crude anhydrous sodium sulfate in the United States occur in Yavapai County, Ariz., about 21 miles from the nearest railroad at Clemenceau. These deposits, 150 ft deep, consist of anhydrous sodium sulfate, glauber salts, other sodium salts, gypsum, and rock salt interbedded with clay. These deposits, now idle, were worked as underground mines and when in production were the largest source of natural sodium sulfate in the country.

Wyoming. There are many deposits of sodium salts, predominantly sulfates, in Wyoming, the most important being in Albany, Carbon, and Natrona counties.

Some of the largest and best known deposits are listed below:

Downey Lakes, Albany County, 22 miles southwest of Laramie. Three lakes covering about 100 acres and having a thickness of 0 to 10 ft. Have been worked.

Union Pacific Lakes, Albany County, 13 miles southwest of Laramie. Four lakes covering about 60 acres and having a thickness ranging from 0 to 40 ft. Have been worked.

Independence Group, Sweetwater Valley, near Independence Rock, Natrona County. Large numbers of lakes in several groups, over a total area aggregating more than 900 acres, and having a thickness ranging from 0 to over 40 ft. Have been worked.

Gill Lakes, 8 miles northeast of Casper, Natrona County. Four lakes having a thickness of over 20 ft in places. Deposits now worked.

It is stated that the Downey Lake deposits contain about 4 million tons of

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sodium sulfate and that the product, after calcining, contains over 95 per cent sodium sulfate, is iron-free, and contains only traces of calcium and magnesium chlorides.

Nevada. Large deposits of sodium sulfate at Rhodes Marsh, 8 miles south of Mina, Nev., worked many years ago are now being exploited by the Nevada Chemical Co., a subsidiary of the Florida Pulp & Paper Co.; and a plant to produce 500 tons per day was reported to be under construction in 1948. Other deposits are known, some of which have been worked. A deposit near Hoover Dam, about 4 miles from St. Thomas, is reported to contain 2 to 4 million tons of glauberite.

North Dakota. Very extensive deposits, the best of which run nearly 95 per cent pure sodium sulfate, were discovered in 1934 in Williams, Divide, and Mountrail counties in northwestern North Dakota. Seven of these deposits contain over 20 million tons of sodium sulfate. They range from $1\frac{1}{2}$ to 7 miles from railroads. There has been no commercial production.

Utah. The brines of Great Salt Lake are estimated to contain 30 million tons of sodium sulfate, and deposits of solid salts, 2 to 30 ft thick and under 18 to 48 in. of overburden, occur on the southern shores of the lake. Some production has been made in past years, but there is none at present.

Texas. Soda Lake, 11 miles south of Monahans in western Texas, is a dry lake bed of about 120 acres with a surface layer of crude glauber salt, 3 to 6 ft thick. Adjacent to it are sources of brines containing sodium sulfate, chloride, and other salts. These sources are reported to contain at least 1 million tons of recoverable sodium sulfate. They have been worked in recent years. Other Texas production has come from Brownfield and O'Donnell.

Washington has numerous deposits of sodium sulfate, both solids and brines, in Grant and Okanogan counties, with an aggregate tonnage of perhaps $1\frac{1}{2}$ million tons. Some of them have been worked in a small way.

*Canada.*⁹ Large lake deposits consisting chiefly of sodium sulfate, but with minor amounts of sodium chloride, magnesium sulfate and carbonate, and other compounds, occur in the provinces of Saskatchewan and Alberta, Canada. Some of the most important of these deposits that have been carefully examined are located at or near the following points in Saskatchewan: Frederick Lake, at Expanse; Fusilier; Whiteside Lake, near Oban and Palo; Muskiki Lake, near Dana; Ingebright district, near Maple Creek and Prelate; Horseshoe Lake, near Viceroy; Chaplin Lake, 60 miles west of Moosejaw. These deposits contain solid crystal beds and nearly saturated brines that, in the dry season, deposit solid crystals, consisting of from 70 to about 95 per cent pure, hydrous sodium sulfate. It is estimated that the deposits so far examined in detail contain 50 million tons of hydrous sodium and magnesium salts, chiefly sodium sulfate, and that other deposits may contain many million tons in addition.

Six recovery plants were in operation in 1948 with an estimated production of 228,000 tons. The latest of these plants was built by the Saskatchewan government in 1946 and 1947 at Chaplin Lake. Designed for a capacity of 150,000 tons per year, it produced a little less than one-third that tonnage, from a single unit, in 1948. The deposit covers about 18.6 square miles, 14 to 24 in. thick, and

contains an estimated 15 million tons of glauber salt. The recovery here is from pumped brines rather than the usual method in Saskatchewan of digging solid crystal with shovels or drag scrapers. Other plants, located at Ormiston, Palo, Bishopric, Alsask, and Gladmar, have annual capacities of from 20,000 to 55,000 tons per year.

Russia.^{3,7} In the vicinity of Minussinsk and Abakansk, in the government of Yeniseisk, Siberia, there are a number of saline lakes that deposit mainly sodium sulfate. The salinity of the waters in these lakes varies from 1 to 15 per cent. The salts are a mixture of sodium sulfate and chloride, with minor amounts of magnesium and other elements, but sodium sulfate predominates. Some of these lake deposits, for example, Lake Altai, have been worked, and the crude glauber salts obtained have been used extensively in neighboring glass factories.

In addition to the lakes noted above, there are other saline lakes in Siberia and elsewhere in Asia containing sulfates, but they are mostly of comparatively low salinity.

Other Countries.^{3,7} In the State of Yucatan, *Mexico*, Lake Chicken Kanab (Little Sea) contains both sodium and calcium sulfates, but its salinity is low (4.446 parts per thousand). In *Rumania*, Lacu Sarat deposits large crystals of mirabilite in winter, which redissolve, at least in part, when the weather becomes warm. In *West Central Asia* the waters of Karabugas Gulf, on the eastern side of the Caspian Sea (with a salinity of 16 to 28 per cent), deposit in winter a layer of mirabilite along the shores. This deposit does not wholly dissolve in summer, but a layer about 0.33 m thick covering 3,500 sq km remains. This deposit is estimated to contain 1,000 million metric tons in round numbers, but its exploitation is hindered by its remote location and unwholesome climatic conditions.

Manufactured Sodium Salts. In 1946 out of the total United States consumption (production plus imports) chemically manufactured salts accounted for about 95 per cent of the sodium carbonate and 76 per cent of the sodium sulfate.

Soda ash or sodium carbonate is produced by the ammonia-soda (Solvay) process, in which the raw materials are common salt (originating in either solid or brine form), limestone, ammonia, and water. Ammonia gas and carbon dioxide (from burning limestone) are bubbled through water, forming ammonium bicarbonate, NH_4HCO_3 . This is reacted with salt, forming sodium bicarbonate, NaHCO_3 , which is calcined to form soda ash. The ammonia, as the chloride, NH_4Cl , is reacted with lime to form ammonia gas for reuse.

Sodium sulfate is manufactured mainly (over 80 per cent in 1939) as a by-product from making hydrochloric acid by reacting common salt and sulfuric acid. Another method, the Hargreaves process, which originated in Europe, reacts lump salt with sulfur dioxide gas, air, and water. It has been made in the sulfate paper-pulp process by calcining soda ash and gypsum with black ash. A so-called "synthetic salt cake" has been made by sintering soda ash and sulfur together as a rather unsatisfactory substitute for true salt for the kraft-paper industry. It is made as a by-product in the viscose process for making rayon, where cellulose is dissolved in caustic soda, which is later neutralized with sulfuric acid. This forms a dilute solution of sodium sulfate that may be recovered by evaporation.

Niter cake, sodium bisulfate, NaHSO_4 , was formerly obtained by the almost obsolete reaction of sodium nitrate with sulfuric acid. This niter cake was once reacted with common salt to form sodium sulfate, but the process is not now operated in this country.

At one time, before the Second World War, imports of manufactured salt cake, chiefly from Germany (reaching a peak of nearly 237,000 tons in 1937) formed a very important part of total United States consumption. Most of this was a coproduct from making hydrochloric acid, but part of it came from the recovery of potash at Stassfurt (see Potash). These imports have not yet (1949) been resumed but they, plus the Canadian production, form a potential threat to the domestic natural sodium sulfate industry.

Glauber salt is the hydrated sodium sulfate made by recrystallization of the salt below 32.4°C . Sodium sulfate crystallizes with 1, 2, 7, and 10 molecules of water, but the crystals with 10 molecules of water are the most common and form the glauber salt of commerce. When pure, glauber salt contains 14.3 per cent Na, 29.8 per cent SO_4 , and 55.9 per cent H_2O . It crystallizes in large transparent crystals having a specific gravity of 1.471, and also in small fine crystals resembling epsom salts. The size of the crystals produced depends upon the conditions maintained during crystallization. If crystallized above 33°C , the anhydrous salt or the monohydrate forms.

Glauber salt has a cooling, bitter, salty taste and is neutral in its chemical reaction. The crystals on exposure to the air lose part or all of their water of crystallization (effloresce). When the salt crystals are dissolved in water, there is a decrease in temperature.

Most of the sodium sulfate is prepared for market in the anhydrous form, and only a small part is converted into glauber salt. This is done to obviate the shipment of the large amount of water of crystallization.

Caustic soda, NaOH , is not found as a natural mineral but is made chemically by one of two processes. The United States production in 1945 was 2,321,769 short tons, a drop of about 6,000 tons from the peak of 1944. Of this total, 57.8 per cent was made by the electrolytic process from common salt and the balance by the lime-soda process from soda ash. Part of the production is shipped in liquid form (or used in producing plants), and part is evaporated and sold as a solid.

In the *electrolytic process* salt brine is treated in an electrolytic cell, producing caustic soda and chlorine gas as coproducts. The one disadvantage of this process is that the production of caustic soda and chlorine are tied together. A decline in demand for either product forces reduced production, perhaps when there is a strong demand for the coproduct.

In the *lime-soda process* soda ash, in solution, is treated with hydrated lime, $\text{Ca}(\text{OH})_2$, forming caustic soda and calcium carbonate. The calcium carbonate may be washed, dried, and sold as a commercial product or recalcined and reused in the process.

In 1945 there were in the United States 39 plants making electrolytic caustic and 9 lime-soda process plants. Caustic soda is used in pulp and paper, detergents, synthetic resins and rubber, the refining of vegetable and mineral oils; and as a base for making many chemicals.

Utilization. Soda Ash. The largest single use for soda ash is in glassmaking. On an average, about 1 ton of soda ash is used in making 5 tons of glass. It is estimated that in 1945 this use alone took 1,320,000 tons of soda ash. The estimated distribution of United States consumption in 1945 is shown in Table 7.¹²

TABLE 7. USES FOR SODA ASH, 1945

<i>Use</i>	<i>Per Cent of Total</i>
Glass.....	29.3
Caustic and bicarbonate.....	24.0
Other chemicals.....	21.3
Nonferrous metallurgy.....	4.9
Pulp and paper.....	3.7
Soap.....	3.1
Water softeners.....	2.2
Cleaners and modified sodas.....	2.0
Textiles.....	1.3
Miscellaneous*.....	8.2
	100.0

* The miscellaneous group includes some minor but essential uses, for example, the recovery of alumina from bauxite in the aluminum industry.

TABLE 8. ESTIMATED Na_2SO_4 END-USE DISTRIBUTION, 1946

<i>Use</i>	<i>Tons</i>
Paper and pulp.....	710,000
Textile.....	75,000
Glass and ceramics.....	50,000
Heavy chemicals.....	50,000
Other.....	45,000
Total.....	930,000

TABLE 9. ESTIMATED CONSUMPTION OF SALT CAKE, TONS

Consumer	1947	1948	1949*
United States, sulfate pulp mills.....	705,700		
Canadian sulfate pulp mills.....	106,500	.....	151,500
Mexican and South American pulp mills.....	6,500		
Total sulfate mills.....	818,800	933,300	997,800
Detergent industry.....	100,000	250,000	300,000
Glass, tanning and dyeing.....	150,000	175,000	175,000
Total requirements.....	1,068,000	1,358,300	1,472,800

* Estimated as of Mar. 10, 1948.

Sodium Sulfate. The largest use for sodium sulfate is in making kraft or sulfate-process paper pulp, which uses around 80 per cent of the domestic consumption. An important and growing use is as an ionizable bulking agent with synthetic detergents in household powdered "soaps." Table 8¹³ shows the estimated end use pattern for United States consumption in 1946.

Holland⁹ estimates the end use pattern for more recent years, as shown in Table 9.

Prices. In 1950, soda ash was quoted at \$1.35 per 100 lb for 58 per cent grade in paper bags; crude niter cake, at \$20 per ton; crude salt cake, at \$22 per ton fob works; glauber salt, crystals, in bags, carload lots, at \$1.60 per 100 lb.

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SPINEL

Composition. Spinel is magnesium aluminate, $\text{Mg}(\text{AlO}_2)_2$ or $\text{MgO} \cdot \text{Al}_2\text{O}_3$: MgO , 28.2 per cent; Al_2O_3 , 71.8 per cent. It often contains iron, manganese, and chromium.

General Description. Spinel is usually found in simple or twinned octahedral crystals either as loose grains or pebbles or in solid rock. There are several important varieties: (1) *ruby spinel* or *balas ruby*, usually transparent; (2) *rubicelle*, yellow or orange-red in color; (3) *blue spinel*, light-blue color; (4) *pleonaste* or *celonite*, an iron-magnesium spinel, dark green, brown or black, and usually opaque; (5) *picotite*, a chrome spinel, black, yellow or greenish brown; translucent to nearly opaque; (6) *gahnite*, which contains zinc; green, brown or black; translucent to opaque; (7) *spinel emery*, which resembles corundum emery.

Physical Properties. *Hardness*, 7.5 to 8. *Specific gravity*, 3.5 to 4.5. *Melting point*, 2117°C (for pure material). *Index of refraction*, $1.723 \pm$ to $2.36 \pm$, depending on composition [$1.723 \pm$ for pure $\text{Mg}(\text{AlO}_2)_2$]. *Color*, red, green, blue, black, brown, yellow. *Streak*, white. *Luster*, vitreous to nearly dull. *Cleavage*, imperfect octahedral. *Transparency*, transparent to opaque. *Tenacity*, brittle.

Occurrence. Spinel is a common mineral, usually of metamorphic origin, but also a constituent of basic igneous rocks. It is usually found in granular limestone, serpentine, gneiss, etc., often associated with corundum, calcite, olivine, graphite, chondrodite, etc. Spinel is also found as grains and rounded crystals in placer deposits. Gem spinels occur in Ceylon, Burma, and Siam. They are also found in many localities in North Carolina, particularly Macon County; at Franklin Furnace, N.J.; and Orange and St. Lawrence counties, N.Y. Spinel emery has been mined near Whittles, Pittsylvania County, Va.

Utilization. The transparent varieties, particularly the red and blue ones, are highly prized as gems. Scientific examination of some of the large rubies of historic interest has disclosed that they are spinels. The spinel emery of Whittles, Va., has been used as an abrasive and is said to be equal in quality to medium-grade Naxos emery. Considerable interest has been displayed in the use of synthetic spinel as a refractory. Such a material was manufactured in California from calcined magnesite and Al_2O_3 derived from alunite.¹ These materials were fused in an electric furnace and crushed and sized to desired dimensions, and the grains bonded into brick or other shapes and burned in kilns. Synthetic spinel of gem quality has been made in quantity by the Verneuil process by which the purified raw materials, MgO and Al_2O_3 , are fused in an oxygen-hydrogen flame and allowed to crystallize on a properly prepared mount forming a boule several inches in length. This boule is crystalline, and since its optical and other physical

properties are essentially identical to crystals formed by nature it supplies a satisfactory substitute. The addition of pigments, cobalt or chromium oxides, permits the manufacture of blue or green synthetic spinel in beautiful colors adaptable to gem use. Other colors may be produced by variation in coloring agents. This material is also suitable for use as a jewel in watches and instruments. It has been reported^{3,4} that during the war German scientists evolved a process by which synthetic spinel jewel bearings could be hardened until they would approximate sapphire bearings in performance. Synthetic spinel contains an excess of Al_2O_3 above the theoretical amount. Upon heating for 12 hr to temperatures varying from 1700 to 1920°F it was found that the excess Al_2O_3 was precipitated in another form and the spinel became cloudy. Hardness increased to such a point that a satisfactory substitute for corundum was available. The expense of production was substantially decreased, for the lower hardness of the spinel made possible its fabrication in one-half the time and with a reduction of 70 per cent of the amount of diamond dust required for the manufacture of jewel bearings from corundum.

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STONE

In this section will be discussed briefly the types of stone that are used for structural purposes, road building, and so on. Stones of all types are so widely distributed that, for many purposes, stones are used close to their source, with little regard for their mineralogical nature. Thus, for concrete aggregate, road material, and so on a great many types and varieties of stone are used almost interchangeably. A discussion of all the kinds of stone used would require a very large amount of space and would serve no useful purpose. Furthermore, adequate descriptions of all the important phases of the stone industries cannot be given here. Many books have already been written covering different phases of this field (see Bibliography) and only a very brief outline will be included in this work.

Varieties of Stone. As noted above, nearly all types and varieties of stone are used commercially, but a few varieties are used much more commonly than others.

These varieties are granite, marble, limestone, sandstone, and basalt or "trap." Petrographically, these variety names have an exact significance, but, commercially, they are often used very loosely. Thus, any light-colored, hard, igneous rock with a texture resembling that of granite is often called granite commercially, regardless of whether it is a true granite or more properly a syenite or porphyry. In the same way, limestone is used to include dolomite, and marble to include serpentine.

Slate is described in a separate section elsewhere in this book. Limestones used for cement manufacture, for lime, and for whiting substitutes are also described in separate sections.

The most common varieties of stone used commercially are briefly defined as follows:

Granite is an igneous, completely crystalline rock of fairly uniform texture, containing distinctly visible grains. It consists essentially of quartz and feldspar, but also usually contains mica or hornblende and numerous minor accessory minerals. The texture varies from fine to coarse grained.

Basalt is a very fine-grained, dark-colored igneous rock consisting essentially of plagioclase feldspar and augite. Basalt and other similar fine-grained, dark-colored, igneous rocks are known commercially as *trap*.

Sandstone is a sedimentary rock consisting essentially of grains of quartz sand, cemented more or less firmly together with clay, silica, calcium carbonate, or iron oxide. Sandstones with a silica cement are usually the strongest and most desired for structural purposes. Some sandstones also contain feldspar (arkose) and mica.

Conglomerate is similar to sandstone in origin and composition, but is made up of cemented gravel, pebbles, and even large boulders instead of sand.

Limestone when pure, consists of calcium carbonate. Commercial limestone often grades into dolomite (calcium-magnesium carbonate) and also usually contains more or fewer impurities such as sand and clay. Sometimes the structure of shells and other marine organisms from which the limestone was derived is more or less preserved in the limestone.

Gneiss is a crystalline, more or less banded rock formed from granite or related rocks by intense pressure and heat. This process is known as "metamorphism."

Schists are finely banded, foliated metamorphic rocks.

Quartzite is a metamorphosed sandstone. Frequently the individual grains of sand have been cemented by the introduction of secondary silica, producing a rock stronger than the original.

Marble is crystalline rock formed by the metamorphism of limestone or dolomite.

Types of Stone Products. Stone is marketed and used in a great variety of forms; some of the more important are listed below. It should be noted that all varieties of stone are not, and cannot, be used in all these forms.

- I. Rough stone
 - 1. Large blocks
 - a. Riprap
 - b. Rubble

- c. Fluxing stone
 - d. Refractories
- 2. Crushed stone
 - a. Road material
 - b. Railroad ballast
 - c. Concrete aggregate
 - d. Terrazzo
 - e. Stucco dash, concrete facing
 - f. Chicken grit
- 3. Pulverized stone
 - a. Mineral fillers
 - b. Fertilizers
 - c. Rock dusting
- II. Dimension stone
 - 1. Building blocks
 - 2. Monumental stone
 - 3. Flagging and curbing
 - 4. Paving blocks
 - 5. Refractories
- III. Ornamental stone
 - Tabletops, urns, benches, vases

Riprap consists of large irregular blocks of stone used in rough heaps or walls for breakwaters, railroad fills, and similar purposes.

Rubble consists of unsquared blocks of stone used in irregular courses in masonry walls and foundations.

Fluxing stone for iron blast furnaces, foundries, and so on consists of pure limestone or, less often, dolomite, broken or crushed to "one-man" size or smaller. Usually, fines smaller than 2 in. are eliminated, and the most desirable size is between 4 and 8 in.

Refractory stone consists of sandstone, ganister, mica schist, soapstone, or other rock that will withstand a moderately high temperature without fusing, cracking, or disintegrating. Such stone may be used in the form of rough blocks; dimension blocks, sawed or otherwise cut to size; or crushed grains; or it may be crushed, mixed with a bond, and made into bricks.

Crushed stone for road material, railroad ballast, and concrete aggregate consists of various types of stone, such as granite, limestone, and trap rock, which have been crushed and sized by screening into various sizes, usually ranging from $\frac{3}{4}$ to $2\frac{1}{2}$ or 3 in. A hard, tough stone is preferred, but availability and cost usually govern the selection.

Terrazzo consists of small chips or pieces of stone, usually marble or limestone, about $\frac{1}{2}$ to $\frac{3}{4}$ in. in diameter, made by crushing and screening. *Terrazzo* chips are used with portland cement in making floors, which are smoothed down and polished after the cement has hardened.

Stucco dash and *concrete block facing* material consists of various types of stone, usually white or brilliantly colored, which have been crushed and screened to sizes ranging from $\frac{1}{8}$ to about $\frac{3}{8}$ in. Many types and colors of stone are used to

produce different color effects. For surfacing concrete face brick, granules as small as $\frac{1}{16}$ in. are often used.

Chicken grit consists of stone, commonly limestone or marble (but other materials, such as feldspar, are often used), crushed and screened to sizes from $\frac{1}{16}$ to $\frac{3}{16}$ in. in diameter.

Pulverized stone, used as mineral filler, is discussed under Mineral Fillers and Adsorbents. Limestone, marble, gypsum, phosphate rock, and to a much smaller extent certain other materials, such as potash shales and feldspars, are crushed and ground to 10 mesh or considerably finer and used for fertilizer purposes.

Building stones, sawed or otherwise, cut to regular sizes and shapes, are made chiefly from limestone, marble, sandstone, and granite.

Monumental Stone. Granite and marble are the chief stones now used for monumental purposes. Probably about 10 times as much granite as marble is used for this purpose. Monumental granite is now the most important branch (by value) of the granite industry.

Flagging and Curbing. Various types of stone, but chiefly sandstone and granite, are split into large thin slabs called flagging and used for sidewalks and so on. The same varieties of stone are also split into thicker slabs and set on edge for curbing.

Paving blocks are usually split by hand from granite, but sandstone blocks are also used to some extent. Limestone paving blocks are now little used.

Ornamental stone includes a considerable number of varieties of stone, usually highly colored or of unusual markings, such as marble, serpentine, and alabaster, which are cut, carved, turned, and polished, forming a great variety of ornamental objects.

Properties upon Which Uses Depend. The properties that stone must possess to adapt it for different uses differ greatly, depending upon the exact nature of the intended use. Thus, stone to be crushed for road-building purposes should be hard and tough and should be obtainable at low cost. For monumental purposes a pleasing appearance, adaptability to carving, polishing, and lettering, and resistance to weathering are most important.

The most important properties upon which uses of a stone depend are its mineralogical and chemical composition, texture, color, strength, hardness, toughness, porosity, specific gravity, and resistance to weathering.

Mineralogical and chemical composition are very important, for upon these properties depend many of the other physical properties, such as hardness, specific gravity, and resistance to weathering.

For structural and ornamental purposes, the general *appearance* of a stone is of great commercial importance. Appearance depends upon *color*, *texture*, and *uniformity*. Popular tastes in stone change gradually so that a particular color and texture of stone, popular at the present time, may be little used some years hence. Thus, the "brownstone fronts" once so popular for city residences are no longer in vogue.

Strength, in structural stone, is usually not of great importance, for most building stones, when unweathered, are sufficiently strong for all ordinary purposes.

For most uses a crushing strength of 5,000 psi is considered satisfactory. Most fresh granites have a crushing strength of 20,000 to 35,000 psi, and many limestones are nearly as strong. Where a stone is to be used in the form of a weighted slab supported only at its ends, as in window and door caps, a fairly high transverse strength is needed.

Hardness, or resistance to abrasion, depends upon the hardness of the component crystals or grains, texture, and, in sandstones, upon the nature of its cement and state of aggregation. Hard stones, such as granite, are difficult to cut and polish, but are not easily worn away. Superior hardness is desirable in stones used for paving blocks and for road material.

Toughness, or resistance to impact, is of particular importance for paving-block and road material.

Porosity affects the durability of a stone or its resistance to weathering. Not only is total porosity important, but also the size of the pores and the degree of permeability affect the resistance of a stone to the action of gases, acid water, freezing, and so on.

The *specific gravity* of common rocks ranges from 2.2 to 2.7, and the weight per cubic foot ranges from 150 to 190 lb, depending upon the nature of the constituent minerals and the porosity.

Another important factor is determining the value and possible uses of a stone is the *size* of blocks that can be readily obtained. This factor is of little importance if a stone is to be used only for crushed stone, except insofar as it affects costs of quarrying; but for structural and monumental purposes it is necessary to be able to obtain a large proportion of big, sound, rectangular blocks. Many structural stone quarries have been abandoned after large expenditures for equipment and development have been made, due to the small proportion of large, sound blocks that could be obtained.

For most uses of stone the item of *cost* is all-important. Stones of various types are so abundant and of such relatively low unit value that high costs may mean inability to compete, and hence failure. Certain types of high-grade ornamental and monumental stones are sometimes marketed successfully, even where costs are high, but in producing rough stone for low-grade uses cost is often the governing factor. For low-grade uses proximity of markets and transportation costs are often more important than the quality of the stone. Stone used for chemical purposes usually must meet exact specifications, and allowances for impurities may be very low.

Ornamental and Building Stone. Ornamental stones display a combination of pleasing pattern and color and are capable of taking a good polish. As noted by Bowles,⁵ the stone industries do not use the term "marble" in the strict sense of being a metamorphic rock. The term is applied to any calcareous rock capable of taking a polish. Susceptibility to polish, therefore, is an important commercial asset. A selected portion of almost any building stone may be used for ornamental purposes. Certain materials are imported from foreign sources. Marble, alabaster, breccia, and onyx from Italy are well known. Without doubt, many stone deposits in the United States are capable of supplying excellent material but are not developed due to the absence of a ready market. The marbles of

TABLE 1. STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1948, BY KINDS
(Quantities approximate)

Year	Granite		Basalt and related rocks (trap rock)		Marble		Limestone	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1944	7,395,390	\$17,200,247	14,043,290	\$17,158,774	152,710	\$4,374,722	115,506,130	\$118,550,317
1945	7,740,030	17,052,764	14,910,540	17,532,775	171,230	5,284,827	112,574,420	121,441,509
1946	11,119,490	29,492,076	16,400,120	20,683,202	205,260	7,919,979	134,717,410	155,649,197
1947	12,443,320	34,123,460	19,616,020	25,755,314	227,880	10,252,522	150,408,820	186,548,286
1948	13,685,880	38,807,266	20,654,580	29,916,965	276,000	10,421,254	166,742,390	215,451,016

Year	Sandstone		Other stone*		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944	6,426,670	\$10,985,211	12,055,390	\$7,372,886	155,579,580	\$175,642,157
1945	4,386,990	8,712,045	13,622,000	9,283,982	153,405,210	179,307,902
1946	4,253,860	11,407,302	12,156,220	9,187,730	178,852,360	234,339,486
1947	6,809,080	16,586,504	18,049,670	16,078,396	207,554,790	289,344,482
1948	7,289,950	18,048,947	16,886,590	16,339,123	225,535,390	328,984,571

* Includes mica schist, conglomerate, argillite, various light-color volcanic rocks, serpentine not used as marble, soapstone sold as dimension stone, and such other stone as cannot properly be classed in any principal group.

STONE

Vermont and Georgia, the granite of Vermont, the marbles of Tennessee, and the limestone of the Bedford, Ind., district are in extensive use over a large portion of the country. In part this is due to the well-established productive capacity of the industry, publicity on a nationwide basis, and general knowledge by the architectural profession of the merits of these materials. A number of public buildings in Washington are outstanding examples of the use of ornamental and building stones. The National Art Gallery with its exterior of Tennessee marble and interior columns of Italian breccia and Indiana limestone is a noteworthy example.

Crushed Stone. Crushed stone is prepared in large tonnages from a variety of rocks. Its use as an aggregate in concrete is the most important market. The absence of natural aggregates, sand and gravel, in many areas makes the use of crushed stone a necessity, and the widespread use of concrete in road building and construction has created a huge market for stone. Crushed stone includes the material sold to industry for use as a raw material. Crushed and sized granules, mostly colored by processes essentially of a ceramic nature, are used for coating asphalt shingles and roofing.

TABLE 2. STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY USES

Use	1945		1946	
	Quantity	Value	Quantity	Value
Dimension stone:				
Building stone:				
Rough construction, short tons.....	155,750	\$ 926,402	208,170	\$ 1,578,668
Cut stone, slabs, and mill blocks, cu ft.	3,038,120	4,558,609	6,654,340	12,189,205
Approx equivalent in short tons.....	225,870		499,050	
Rubble, short tons.....	390,430	548,645	293,430	649,604
Monumental stone, cu ft.....	3,038,870	11,360,627	3,677,920	17,434,556
Approx equivalent in short tons.....	250,850		300,700	
Paving blocks, number.....	212,570	22,336	578,750	50,346
Approx equivalent in short tons.....	1,560		5,270	
Curbing, cu ft.....	158,260	203,797	374,900	544,477
Approx equivalent in short tons.....	12,760		30,460	
Flagging, cu ft.....	268,480	228,222	475,620	525,364
Approx equivalent in short tons.....	21,470		38,130	
Total dimension stone (quantities approx) short tons.....	1,058,690	\$ 17,848,638	1,374,580	\$ 32,972,220
Crushed and broken stone:				
Riprap, short tons.....	4,801,170	\$ 5,589,584	3,847,550	\$ 5,010,207
Crushed stone, short tons.....	85,373,260	80,429,619	107,267,250	110,892,504
Furnace flux (limestone), short tons.....	27,639,520	22,076,393	25,157,760	20,791,833
Refractory stone*, short tons.....	2,526,650	4,545,339	2,088,080	4,157,179
Agricultural (limestone), short tons.....	17,395,570	25,892,317	22,781,750	32,482,907
Other uses, short tons.....	14,610,350	22,926,012	16,335,390	28,032,636
Total crushed and broken stone, short tons.....	152,346,520	\$161,459,264	177,477,780	\$201,367,266
Grand total (quantities approx), short tons.....	153,405,210	179,307,902	178,852,360	234,339,486

* Ganister (sandstone), mica schist, soapstone, and dolomite.

TABLE 3. CRUSHED AND BROKEN STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1945 TO 1946, BY PRINCIPAL USES

Use	1945			1946		
	Short tons	Value		Short tons	Value	
		Total	Avg		Total	Avg
Concrete and road metal..	64,108,190	\$ 65,535,403	\$1.02	90,358,900	\$ 97,765,446	\$1.08
Railroad ballast.....	21,265,070	14,894,216	0.70	16,908,350	13,127,058	0.78
Metallurgical.....	27,639,520	22,076,393	0.80	25,157,760	20,791,833	0.83
Alkali works.....	7,076,330	4,068,060	0.57	7,418,690	5,230,804	0.71
Riprap.....	4,801,170	5,589,584	1.16	3,847,550	5,010,207	1.30
Agricultural.....	17,395,570	25,892,317	1.49	22,781,750	32,482,907	1.43
Refractory (ganister, mica schist, dolomite, soap-stone).....	2,526,650	4,545,339	1.80	2,088,080	4,157,179	1.99
Asphalt filler.....	455,360	971,570	2.13	459,020	1,270,734	2.77
Calcium carbide works....	549,510 ^a	639,833 ^a	1.16 ^a	411,660	437,231	1.06
Sugar factories.....	340,310 ^a	691,922 ^a	2.03 ^a	378,720	693,058	1.83
Glass factories.....	556,610 ^a	937,615 ^a	1.68 ^a	648,250	1,163,161	1.79
Paper mills.....	352,990	620,943	1.76	385,620	685,912	1.78
Other uses.....	5,279,240	14,996,069	2.84	6,633,430	18,551,736	2.80
	152,346,520	\$161,459,264	\$1.06	177,477,780	\$201,367,266	\$1.13
Portland and natural cement and cement rock ^b .	27,332,000	"	.....	43,877,000	"	
Lime ^d	11,841,000	"	.....	11,985,000	"	
Total stone.....	191,520,000	"	.....	233,340,000	"	
Asphaltic stone.....	642,600	\$ 2,565,925	3.99	777,457	\$ 2,861,591	3.68
Slate granules and flour..	482,230	3,687,173	7.65	663,520	5,424,604	8.18

^a Revised figure.

^b Value reported as cement in section on Cement.

^c No value available for stone used in manufacture of cement and lime.

^d Value reported as lime in section on Lime.

TABLE 4. ROOFING GRANULES* SOLD OR USED IN THE UNITED STATES, 1944 TO 1948, BY KINDS

Year	Natural		Artificially colored		Brick		Total	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1944	287,080	\$2,210,379	637,090	\$ 9,313,356	65,830	\$1,005,964	990,000	\$12,529,699
1945	355,840	2,628,052	628,220	9,124,891	61,220	947,637	1,045,280	12,700,580
1946	447,910	3,470,411	877,990	12,939,512	54,660	866,174	1,380,560	17,276,097
1947	504,980	4,166,810	1,133,870	17,559,227	56,570	988,434	1,695,420	22,724,471
1948	448,150	3,828,307	1,002,430	16,563,251	35,110	586,173	1,485,690	20,977,831

* Manufactured from stone, slate, slag, and brick.

STONE

The tonnages of various types of stone are shown in Table 1. The tonnage distributed by use for the last two years for which figures are available is shown in Table 2. The distribution of crushed stone by industrial use is given in Table 3, and Table 4 shows the tonnage and value of granules in recent years.

Chemical Stone. Limestone is the most useful industrial stone, and its use in the chemical industries is of growing importance.⁶ Besides its importance in the cement and lime industries as reported in the sections concerned with those subjects, it is indispensable in the manufacture of glass and calcium carbide and in many other industries. It also supplies the carbon dioxide for the alkali works engaged in the production of sodium carbonate. Quarries operated for

TABLE 5. LIMESTONE (CRUSHED AND BROKEN STONE) SOLD OR USED BY PRODUCERS IN THE UNITED STATES FOR MISCELLANEOUS USES, 1945 TO 1946

Use	1945		1946	
	Short tons	Value	Short tons	Value
Alkali works.....	7,076,330	\$4,068,060	7,418,690	\$5,230,804
Calcium carbide works.....	549,510	639,833	411,660	437,231
Coal-mine dusting.....	216,160	680,723	208,830	632,729
Filler (not whiting substitute):				
Asphalt.....	455,360	971,570	459,020	1,270,734
Fertilizer.....	410,160	661,348	553,680	1,076,728
Other.....	138,750	428,991	220,370	645,440
Filter beds.....	20,920	38,322	16,410	33,324
Glass factories.....	556,610 ^a	937,615 ^a	648,250	1,163,161
Limestone sand.....	615,400	482,093	622,230	437,882
Limestone whiting ^b	343,220	2,905,637	405,380	3,523,025
Magnesia works (dolomite) ^c ..	295,540	373,919	294,360	464,730
Mineral food.....	291,580	1,310,757	373,630	1,697,507
Mineral (rock) wool.....	39,170	39,575	22,200	23,400
Paper mills.....	352,990	620,943	385,620	685,912
Poultry grit.....	114,670	751,469	117,630	822,985
Refractory (dolomite).....	1,027,099	1,120,136	1,035,110	1,146,864
Road base.....	298,930	233,979	283,820	252,806
Stucco, terrazzo, and artificial stone.....	25,500	148,332	25,830	171,113
Sugar factories.....	340,310 ^a	691,922 ^a	378,720	693,058
Other uses ^d	199,800	300,319	447,350	543,291
Use unspecified.....	305,250	423,321	753,930	1,010,884
	13,664,340	\$17,828,864	15,082,720	\$22,054,628

^a Revised figure.

^b Includes stone for filler for calcimine, calking compounds, explosives, foundry compounds, glue, insecticides, leather goods, linoleum, paint, paper, phonograph records, plastics, pottery, putty, roofing, rubber, tooth paste, wire coating, and unspecified uses.

^c Includes stone for refractory magnesia.

^d Includes stone for acid neutralization, athletic-field marking, carbon dioxide, chemicals (unspecified), concrete blocks and pipes, dyes, electric products, fill material, magnesium metal, motion-picture snow, oil-well drilling, rayon, spalls, waste rock, and water treatment.

this market actually should be called carbon dioxide quarries, since this is the product desired and the lime is incidental. Silica from sandstone or glass sand is of growing importance as a chemical raw material. In addition to its role in glassmaking it is used in the manufacture of sodium silicates, silicon carbide, and the remarkable silicones whose properties are just beginning to be appreciated.

The industrial distribution of limestone is illustrated in Table 5.

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STRONTIUM MINERALS

The only strontium minerals that occur in sufficient abundance to be of commercial interest are celestite and strontianite. Celestite is by far the more common and is the principal mineral mined for conversion into strontium salts and use without alteration. In spite of the fact that large deposits of strontium

STRONTIUM MINERALS

minerals are known in the United States, production has never been important—first because there is little domestic demand other than the abnormal periods associated with war, when normal commerce is impossible; second; because the more important domestic deposits are not readily accessible; third; the low price at which imported ores and salts may be laid down on the Atlantic coast has discouraged mining in this country.

CELESTITE

Composition. Celestite is strontium sulfate, SrSO_4 : SrO , 56.4 per cent; SO_3 , 43.6 per cent. In commercial deposits it is rarely pure, often containing more or less barium, calcium, and sodium.

General Description. Celestite is a heavy, white to bluish mineral resembling barite. It usually occurs in tabular or prismatic orthorhombic crystals or as fibrous, cleavable masses. Sometimes it occurs as a massive fine-grained crystalline rock resembling buff-gray limestone, except that it is heavier. It was first discovered near Bellwood, Pa., where it occurs in the partings of a shaly limestone in thin seams. It is pale blue in color and fibrous in structure, resembling the variety of gypsum known as "satin spar."

Physical Properties. *Hardness*, 3 to 3.5. *Specific gravity*, 3.9 to 4.0. *Melting point*, 3 in scale of fusibility. *Index of refraction*, 1.622 to 1.631. *Color*, generally white with bluish tinge, also yellowish or reddish. *Streak*, white. *Luster*, vitreous to pearly. *Cleavage*, perfect basal and prismatic (angles about 104 and 76 deg). *Fracture*, uneven. *Transparency*, translucent to opaque; rarely, nearly transparent. *Tenacity*, brittle.

STRONTIANITE

Composition. Strontianite is strontium carbonate, SrCO_3 : SrO , 70.1 per cent; CO_2 , 29.9 per cent. It usually contains some calcium and barium.

General Description. Strontianite is typically found in white, pale-green, or yellowish groups of radiating, needle-shaped crystals and also in fibrous or, more rarely, granular masses.

Physical Properties. *Hardness*, 3.5 to 4.0. *Specific gravity*, 3.6 to 3.8. *Melting point*, 5 in scale of fusibility. *Index of refraction*, 1.520 to 1.667. *Color*, white, gray, pale green, or yellowish; also colorless. *Streak*, white. *Luster*, vitreous. *Cleavage*, imperfect prismatic. *Fracture*, conchoidal. *Transparency*, translucent to transparent. *Tenacity*, brittle.

Table 1 shows the analyses of typical material as given by Harness.³

Occurrence. *United States.* Details of the occurrences of celestite in California and Arizona are presented in Refs. 4 and 5. Much of the domestic production of the war years was shipped from Westmorland and Ludlow, Calif.

California. In California, very large deposits of celestite are reported on the northeast side of the Avawatz Mountains, about 10 miles west of the Tonopah and Tidewater Railroad and about 15 miles southwest of the Tecopa station, San Bernardino County. Here occur a tilted series of old lake beds, consisting of rock salt, gypsum, and celestite dipping 45 to 70 deg. The celestite zone has a maximum thickness of 75 or 80 ft. In this zone are beds of celestite interlain and

TABLE 1

Celestite (England)		Strontianite	
	Per cent		Per cent
SrSO ₄	96.55	SrCO ₃	90.9
SrCO ₃	0.17	CaCO ₃	7.5
BaSO ₄	0.25	BaCO ₃	0.1
CaSO ₄	0.54	Fe ₂ O ₃	0.05
MgCO ₃	0.15	Al ₂ O ₃	0.1
Fe ₂ O ₃ }	0.90	SiO ₂	0.04
Al ₂ O ₃ }		S.....	0.1
SiO ₂	1.38	P.....	0.005

sometimes intermixed with beds of sandstone, gypsum, or igneous flows. Celestite varies in color from white through pink to a very dark brown. Sandy and clayey impurities are present, but ore analyzing 85 to 91 per cent SrSO₄ may be obtained.

About 31 miles west of Brawley on the Southern Pacific Railroad, near the line between Imperial and San Diego counties, occurs a deposit of celestite above a thick bed of gypsum. It is reported that the ore is low in calcium and barium, and analyses show 94 to 97 per cent SrSO₄.

Strontianite occurs in important quantities about 10 miles north of Barstow, San Bernardino County, in a group of hills locally known as Mud Hills. It is found in thin layers (up to 3 ft thick) and masses, together with beds of limestone and shale in thick beds of grayish-green, gypsiferous, calcareous clay, which are overlain by highly indurated beds of calcareous tuffs, rhyolite tuffs, sandstone, and limestone. The strontianite occurs in two forms: first, as fibrous, radial, or spherulitic masses of resinous color and luster; and, second, as dense, exceedingly fine-grained, gray or drab material resembling limestone. Some of the ore is of very low grade, but a product running 78 to 87 per cent SrCO₃ can be produced. It is stated that deep mining is impractical, due to the loose, unconsolidated condition of the clays, but that a considerable quantity of ore may be obtained by open-cut mining.

Celestite has also been found north of Lavié and Stagg stations of the Atchison, Topeka and Santa Fé Railroad in San Bernardino County.

Arizona. Deposits of celestite occur about 15 miles south of Gila Bend, Maricopa County, Ariz. Here sedimentary beds of conglomerate, sandstone and gypsum, dipping 45 to 70 deg, contain celestite-bearing beds 40 to 50 ft thick, of which the upper 8 or 10 ft are the richest in strontium minerals. Some of the best ore contains 86 to 87 per cent SrSO₄, but it is reported that much of the material is too high in barium and calcium to be of commercial value.

Texas. Celestite has been reported near Strickling, Burnet County, near Lampasas, Lampasas County, and near Austin and Mount Bonnell, Travis County. Strontianite is, in places, found with the celestite. Celestite, in small quantities, has been shipped from the Mount Bonnell district. It is reported

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that the richest ores do not contain more than 10 per cent SrSO_4 , and many of them contain only 1 to 5 per cent. When properly concentrated, however, a marketable grade can be produced.

Utah. Deposits of celestite occur in Emery County about 50 miles from the Denver and Rio Grande Railroad at Green River, Utah. Another deposit is reported in Grand County, about 25 miles southeast of Green River.

Washington. Celestite and strontianite of commercial grade and in deposits of workable size are reported 1 mile southwest of La Conner, Skagit County. Another deposit is stated to occur just above the gorge of Skagit River near the mouth of Ruby Creek.

Other States. Celestite is a common constituent of many of the limestones and dolomites of Ohio, Michigan, New York, and Pennsylvania. Shipments have been made from Ohio. Frequently it is found altered in part to elemental sulfur, probably by bacterial action.

Great Britain. Great Britain normally is the most important miner of strontium minerals. Most of the production is located in Gloucestershire, and exports leave the port of Bristol. Mining consists of small open pits seldom over 20 ft in depth. The celestite is removed and hand trimmed to lump size, which is generally preferred by the trade. The entire operation is small, sporadic, and so conducted as not to interfere with the agricultural use of the surface.

Germany. Strontianite is found in Westphalia in veins varying in thickness from 1 in. to 7 ft. The veins are nearly vertical and are worked by overhead stoping. The crude run-of-mine rock contains from 10 to 15 per cent strontianite. Hand sorting and concentration are necessary to produce commercial material. This runs about 85 per cent SrCO_3 . Strontianite is preferred for some uses due to the ease with which it can be dissolved. However, it tends to contain a high percentage of calcium carbonate and this is objectionable for some uses.

Canada. Strontium ores, both celestite and strontianite, occur at a number of localities in Canada, but only four occurrences, all of celestite, are known of possible commercial importance.⁷ These deposits are all in Ontario, the largest being in the township of Bagot, Renfrew County. Except for a small production from a deposit in Lansdowne, Leeds County, many years ago, the entire Canadian production of strontium ores, all celestite, was obtained from the Bagot deposit during 1919 to 1920.

This deposit is 5 miles by road southeast of Calabogie station on the Kingston and Pembroke branch of the Canadian Pacific Railway. The celestite occurs in irregular slablike masses of radiated, columnar or fibrous crystals enclosed in brown dolomite, between limestone walls that dip 45 to 60 deg southwest. The celestite masses average from a few inches to a foot in thickness, but sometimes reach 2 or 3 ft. The dolomite-celestite breccia shows a thickness of about 45 ft at the main pit. The length and depth are unknown, but seem to be of considerable extent. Over the whole width of the dolomite-celestite breccia the celestite content seems to be not over 10 per cent, but of the 15 ft worked on the hanging-wall contact the content may be as high as 20 per cent. Probably 30 per cent of the celestite can be recovered by hand sorting, but the other 70 per cent requires milling.

Table 2 shows that the celestite contains considerable barite and might more properly be termed baryto-celestite.

TABLE 2. ANALYSES OF CELESTITE FROM BAGOT, ONTARIO, CANADA

	1	2
Strontium sulfate.....	85.63	78.50
Barium sulfate.....	14.38	18.61
Calcium sulfate.....	Trace	0.73
	100.01	97.81

1. Selected material. Analyzed by R. A. A. Johnson, Geol. Survey.

2. Representative sample from stock pile. Analyzed by E. A. Thompson, Mines Branch.

Other Countries. Mexico and Spain are commercial producers. A discovery of large tonnage has been reported recently in India. It is probable that the total world reserves are large and may become of greater value if more important uses are found for strontium.

Production and Consumption. According to the U.S. Bureau of Mines in 1940 there had been no production of strontium minerals in the United States since 1918 except for a small quantity produced in Texas and used in the petroleum industry for drilling mud. This was altered by the war, which interfered with imports while the demand was increasing. Mines were opened in the United States; most of the production came from California, Texas, Washington, and Ohio. The industry was active for a few years, but by 1946 had nearly disappeared. The record of production is shown in Table 3.

TABLE 3. SHIPMENTS OF CELESTITE FROM MINES IN THE UNITED STATES AND IMPORTS

Year	Tons	Value	Imports, short tons
1946	243	\$ 3,726	4,507
1945	2,784	27,740	3,691
1944	3,005	48,165	5,793
1943	7,566	114,526	16,881
1942	4,041	55,529	4,041
1941	4,724	69,054	4,724
1940	350 or less		2,751

Postwar consumption of strontium minerals tends to increase. In 1948 imports of 21,771 short tons were reported. Two-thirds of this tonnage came from Spain.

Utilization. The most important single use of strontium is in the manufacture of red signal flares or fusees. These are used as a warning signal by trains, trucks, ships, and aircraft. Harness³ gives the following formula for the composition of a red fusee:

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	<i>Per Cent</i>
Strontium nitrate.....	71.1
Potassium perchlorate.....	13.1
Sulfur.....	11.1
Sawdust.....	4.2
Charcoal.....	0.5
	<hr/> 100.0

Strontium salts are used in the preparation of tracer bullets, and this use accounts in part for the increased demands characteristic of the war years. Many chemical compounds are prepared that find their way into many useful industrial applications. Refs. 1, 2, and 8 describe a process by which celestite is converted to the carbonate. The mineral is crushed, dried, ground, and heated with a sodium carbonate solution. The strontium carbonate produced by the reaction is filtered from the sodium sulfate liquor, purified to remove traces of barium and calcium salts, and then may be converted to other strontium salts. Strontium greases are reported to be stable from 300 to 400°F and water and hydrocarbon resistant.⁹ Small amounts of celestite are used in ceramic glazes and as a flux on welding rods. The largest use for crude celestite has been in the preparation of oil-well drilling muds. Its gravity, 3.9 to 4.0, is slightly under that of barite. During the war considerable tonnage of celestite was substituted for barite for this use.

In the past the greatest industrial use for strontium minerals has been in the German beet-sugar industry where strontium hydrate is used in desaccharizing beet-sugar molasses by the Scheibler process. Ground celestite has been used in fairly large quantities for purifying caustic soda in the rayon industry. Strontianite has been used on a semicommercial scale in Europe for desulfurizing and dephosphorizing steel. The use of strontium chloride in gas refrigeration was attempted some years ago but failed to develop.

Prices. In 1950 celestite was quoted at \$54 per ton in carload lots for 92 per cent material, finely powdered; strontianite, \$55 per ton for lump material averaging 84 to 86 per cent strontium carbonate.

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SULFUR

Elemental Sulfur, Pyrite, and Other Sources

Elemental sulfur encounters increasing competition from by-product material recovered mostly during the smelting of pyritic copper ores or the sulfides of lead and zinc. In addition, pyrite is mined in large tonnages as a source of sulfur alone. Since all sources of sulfur tend to compete mutually and their economic problems are shared in common, it seems desirable to combine the discussion of the various sources in one discussion.

ELEMENTAL SULFUR

Composition. Sulfur (also known as brimstone) is elemental sulfur (S), sometimes containing traces of arsenic, selenium, or tellurium and often mixed with clay or bitumen.

General Description. Sulfur is a relatively soft mineral, usually of a characteristic yellow color, but sometimes greenish or grayish due to impurities. It occurs in transparent to translucent orthorhombic pyramidal crystals, also in granular, fibrous, earthy, powdery, or stalactitic masses.

Sulfur crystallizes from a molten condition in monoclinic forms.

Physical Properties. *Hardness*, 1.5 to 2.5. *Specific gravity*, 1.9 to 2.1. *Melting point*, 110.2 to 119.25°C, depending on conditions. *Boiling point*, 444.6°C. *Ignition temperature*, 248°C. *Index of refraction*, 1.950 to 2.240. *Color*, yellow to yellow-brown, also reddish, greenish, brownish, or grayish, due to impurities. *Streak*, white to yellow. *Luster*, adamantine on crystal faces; otherwise resinous to greasy. *Cleavage*, indistinct parallel to base, prism and pyramid. *Fracture*, conchoidal to uneven. *Transparency*, transparent to translucent. *Tenacity*, brittle. *Solubility*, insoluble in water and acids; soluble in carbon disulfide. *Nonconductor* of heat and electricity.

Occurrence. The most important commercial deposits of sulfur occur in sedimentary beds with gypsum, anhydrite, and limestone associated with hydrocarbons, carbonates, and sulfates. The sulfur is believed to result from the reduction of sulfates, although the identity of the reducing medium is not clearly understood. It is commonly believed to be bacteria, although chemical reduction by other means is possible. Deposits of this type are those of Texas and Louisiana; Sicily; Conil (near Cadiz), Spain; Bex, Switzerland; and Cracow, Poland.

Superficial deposits of sulfur are found near hot springs, formed by the oxida-

tion of H_2S . Some of these are workable, for example, at Cody, Wyoming; Cove Creek, Utah; Cuprite, Nevada; and Sulphur Bank, California.

Sulfur is sometimes formed at the craters of volcanoes by the oxidation of hydrogen sulfide or by the interaction of sulfur dioxide fumes given off by the volcano. Such deposits are usually small and consist largely of fissure fillings, but they are sometimes workable, as in Hokkaido and in the island of Kyushu, Japan; Mount Olca and Mount Chupiquiña, Chile; and in the vicinity of Lake Rotorua, New Zealand.

Deposits of sulfur of no commercial importance are formed by the alteration of sulfides, such as pyrite and galena.

Most of the world's needs for sulfur are supplied by deposits in the United States, Sicily, and Japan, named in the order of their importance. Sulfur deposits are worked in many other countries, notably Spain, Chili, Mexico, France, and Turkey, but their total output is small.

United States. The United States is now by far the largest sulfur producer of the world, the production in 1946 being 92 per cent of the world's output. This position, however, has been held only since 1916. Prior to 1904 most of the sulfur used in this country was imported from Italy. In 1904 and 1905 the mining of sulfur by the Frasch process was begun in Louisiana and since that time most of the domestic requirements for sulfur have been supplied from domestic sources.

The Frasch process was patented in 1890. It consists briefly of the injection of hot water, $160^{\circ}C$, into sulfur-bearing strata. The sulfur is melted by heat transfer and thereby is enabled to migrate to a position from which it is lifted by air to the surface. By 1901 sulfur was produced in quantity by this process and thereafter led to a rapid increase in production. The process is applied to the salt domes of the Gulf Coast area. The presence of sulfur in these domes was discovered in oil-drilling exploration. The recovery of sulfur by mining methods was not successful. The domes are formed by the plastic deformation of salt, producing a domelike structure, at times exposed at the surface by erosion. Over 300 domes are known, less than 5 per cent being considered suitable for the production of sulfur. The sulfur is found associated with anhydrite and gypsum, which is found near the apex of the dome. The sulfur-bearing zone is usually found at depths varying from 600 to 1,200 ft. Well drilling for the Frasch process is, therefore, not especially difficult.

Present methods of operation of the Frasch process have recently been described by one of the largest producers as follows:

The well equipment consists of pipes of various sizes, placed one within the other and extending from the surface into the sulfur deposit. A 10- or an 8-in. casing extends to and rests on the top of the cap rock. A 6-in. pipe, inside the casing, passes below it and reaches into the barren anhydrite. It is perforated at two different levels, separated by an annular collar. The upper set of perforations permits the hot water to enter the sulfur formation and the lower set permits the entrance of the molten sulfur to the discharge pipe fitted inside the 6-in. pipe.

When a well is "steamed" the hot water passes down the annular space inside the 6-in. pipe and outside the sulfur pipe and flows through the upper set of perforations into the porous formation. The entire mass through which the hot water circulates

is raised to a temperature above the melting point of sulfur. The liquid sulfur, being heavier than water, makes its way downward to form a pool and displaces water around the foot of the well, and rises in the well column through the lower perforations into a 3-in. pipe, which is the sulfur discharge pipe. Compressed air released at the bottom of still another pipe fitted inside the 3-in. pipe rises and mixes with the sulfur column, forming an air lift that raises the liquid sulfur free of water to the surface.*

The Frasch process requires a substantial capital investment before recovery of marketable material. The deposits must have a certain minimum content of recoverable sulfur, the rock structure must possess sufficient permeability to allow penetration of water and flow of molten sulfur, and the hot water must be in contact with the sulfur long enough to produce fusion. The accumulation of water in quantity sufficient for operation, at times millions of gallons per day, may be a serious problem. Supplies are secured from wells and storage of surface water. The molten sulfur is pumped into large vats up to 1,220 ft long, 200 ft wide, and 50 ft high. The solidified sulfur is blasted into fragments for loading to cars for shipping. It exhibits a remarkable purity, 99.5 to 99.9 per cent. The disposal of spent water is a problem, since it cannot be drained into streams ordinarily. At times it must be stored, treated to remove sulfides, and wasted to streams during periods of rain and high water. In some cases it is treated and then conveyed by ditch to tidewater, a distance of miles. The Frasch process is illustrated in Fig. 14.

Some sulfur is produced in California, Colorado, and Nevada. The domination of production from the domes of Louisiana and Texas is exhibited in Table 1.

TABLE 1. SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, 1944 TO 1948*

Year	Produced, long tons				Shipped	
	Texas	Louisiana	California and Utah	Total	Long tons	Approximate value
1944	2,582,238	635,920	.....	3,218,158	3,519,083	\$56,300,000
1945	2,969,778	783,410	.....	3,753,188	3,833,294	61,300,000
1946	2,975,472	884,170	.....	3,859,642	4,128,212	66,100,000
1947	3,561,214	880,000	.....	4,441,214	4,828,103	85,200,000
1948	3,867,545	1,001,665	.....	4,869,210	4,978,912	89,600,000

* In addition to the refined sulfur shown, native sulfur ore (10–70 per cent S) for agriculture use was produced in Colorado and Texas in 1942–1948 and in California and Nevada in 1946. Total shipments of this material were as follows, in long tons: 1942, 1,590 (\$16,000); 1943, 2,572 (\$26,215); 1944, 1,639 (\$8,950); 1945, 1,426 (\$12,170); 1946, 6,344 (\$95,531).

Utilization. The consumption of sulfur in the United States is given in Table 2.

The very high dielectric property of sulfur has never been used appreciably, due to the ease with which the material ignites.

* Advertisement of the Texas Gulf Sulphur Co., June, 1949.

SULFUR

The largest use for sulfur, whether elemental or derived from pyrite or other sources, is in the making of sulfuric acid. It is estimated that about 75 per cent of the elemental sulfur produced and a much larger percentage of sulfur from other sources is converted to sulfuric acid. Table 3 shows the approximate consumption of sulfuric acid by major consuming industries.

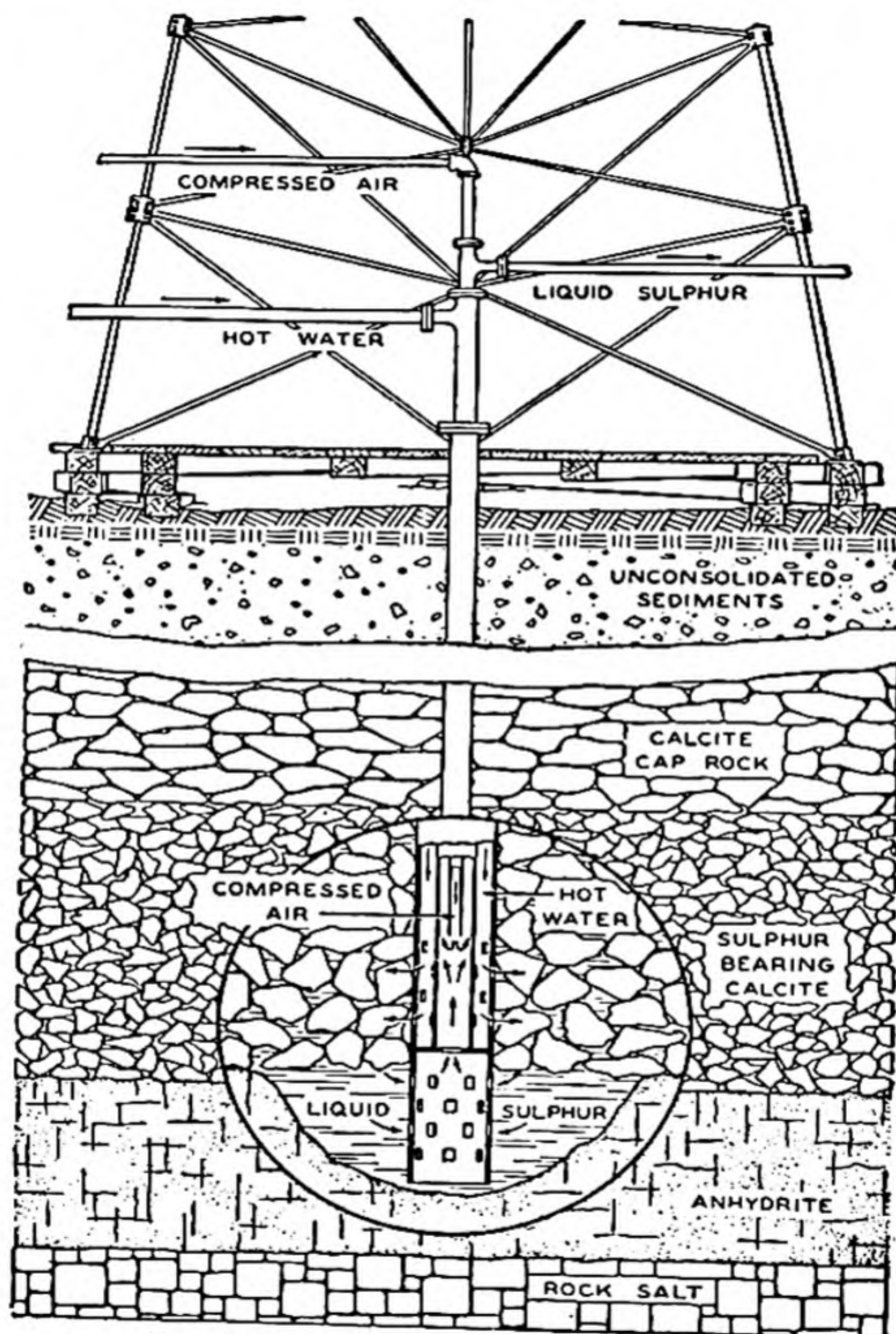


FIG. 14. Diagram of the Frasch process.

Price. In 1950 sulfur was quoted per long ton fob Texas at \$18 for the domestic market.

Production. Italy. Until the extensive development of the sulfur deposits of Louisiana and Texas the Italian production of sulfur dominated the world markets. From 1860 to 1905 Italian production showed an almost con-

stant increase, reaching a maximum of 568,927 metric tons in 1905. From 1906 to 1917 production almost steadily decreased to 211,847 tons in that year. From 1918 to 1921 production again slowly increased to 284,600 tons in 1921. This great decline has been due to several causes, the most important of which

TABLE 2. SULFUR CONSUMED IN THE UNITED STATES, 1944 TO 1948, BY USES, LONG TONS
(Chemical Engineering)

Use	1944	1945	1946	1947	1948
Chemicals*	1,585,000	1,605,000	1,460,000	1,760,000	1,790,000
Fertilizer and insecticides.....	580,000	600,000	620,000	740,000	800,000
Pulp and paper.....	300,000	297,000	305,000	370,000	380,000
Explosives*.....	88,000	90,000	90,000	100,000	110,000
Dyes and coal-tar products...	75,000	75,000	80,000	95,000	98,000
Rubber.....	55,000	58,000	65,000	65,000	63,000
Paint and varnish.....	90,000	94,000	105,000	190,000	240,000
Food products.....	7,000	7,000	7,000	8,000	8,000
Miscellaneous.....	140,000	135,000	175,000	212,000	211,000
Total.....	2,920,000	2,961,000	2,907,000	3,540,000	3,700,000

* To avoid disclosing estimated consumption of sulfur in direct war applications, such as military explosives, sulfur so used is included under Chemicals.

TABLE 3. SULFURIC ACID (BASIS, 100 PER CENT) CONSUMED IN THE UNITED STATES, 1944 TO 1946, BY INDUSTRIES, SHORT TONS
(Chemical Engineering)

Industry	1944	1945	1946
Fertilizer.....	2,640,000	2,850,000	3,020,000
Petroleum refining.....	1,020,000	1,020,000	1,000,000
Chemicals and defense*.....	2,490,000	2,229,000	1,780,000
Coal products.....	625,000	600,000	510,000
Iron and steel.....	560,000	570,000	475,000
Other metallurgical.....	350,000	330,000	280,000
Paints and pigments.....	510,000	520,000	550,000
Industrial explosives.....	120,000	100,000	105,000
Rayon and cellulose film.....	450,000	495,000	556,000
Textiles.....	75,000	70,000	75,000
Miscellaneous.....	350,000	400,000	345,000
Total.....	9,190,000	9,175,000	8,696,000

* To avoid disclosing estimated consumption of acid in direct war applications, such as military explosives, acid so used is combined with Chemicals.

have been the enormously increased production and the low costs of production in the United States. Other causes have been (1) a rather short-sighted policy regarding prices, which caused extensive substitution of pyrite for sulfur in the manufacture of sulfuric acid; (2) the failure to discover new deposits; (3) the

TABLE 4. WORLD PRODUCTION OF NATIVE SULFUR, 1939 TO 1946, BY COUNTRIES, LONG TONS^a
(Compiled by P. Roberts)

Country ^a	1939	1940	1941	1942	1943	1944	1945	1946
Argentina.....	.....	.....	367	2,148	10,649	11,092	^b	^b
Bolivia (exports).....	2,126	4,065	2,315	3,535	7,079	6,151	640	468
Chile.....	26,999	32,440	28,745	29,570	32,360	30,380	28,617	^b
Ecuador.....	72	.....	^b	.....	61	13	102	26
France (content of ore).....	689	309	575	703	1,000	1,021	2,923 ^c	5,610 ^c
Greece.....	.....	2,239	1,585	4,685	6,373	1,860	448	87
Guatemala.....	12	11	^b	10 ^d	10 ^d	.....	^b	^b
Italy (crude) ^e	350,208	325,473	294,288	220,808	91,773 ^f	37,000 ^d	80,000 ^d	140,765
Japan ^g	202,562 ^h	192,357 ^h	198,056 ⁱ	160,917 ^h	145,368 ^h	70,394 ^h	21,088 ^h	21,051
Mexico.....	^b	^b	^b	26,115 ^c	4,400 ^c	5,100 ^c	7,100 ^c	^b
Netherlands Indies.....	17,293	16,908	^b	^b	^b	^b	^b	^b
Palestine.....	829	1,358	3,365	713 ^c	^b	^b	^b	^b
Peru.....	571	610	935	1,126	564	601	1,197	394
Spain.....	3,770	3,560	6,230	5,000	5,511	6,280	4,840	^b
Turkey ⁱ	2,560	2,600 ^d	2,600 ^d	2,000 ^d	3,326	3,348	3,097	376
United States.....	2,090,979	2,732,088	3,139,253	3,460,686	2,538,786	3,218,158	3,753,188	3,859,642
Total ^j	2,700,000	3,300,000	3,700,000	4,000,000	3,000,000	3,500,000	4,000,000	4,200,000

^a Native sulfur believed to be produced also in China, Cuba, Egypt, Formosa, India, Iran, and U.S.S.R., but complete data are not available; however, estimates by senior author of this chapter are included in total.

^b Data not available; estimate by senior author of this chapter included in total.

^c Incomplete data.

^d Estimate.

^e In addition, following quantities of sulfur rock reported: 1939, 19,568 tons; 1940, 15,552 tons; 1941, 17,802 tons; 1942, 30,734 tons.

Similar data not available for later years.

^f Production of Sicily for fiscal year ended July 31 of year stated.

^g Preliminary data.

^h Fiscal year ended Mar. 31 of year following that stated.

ⁱ Data cited appear to be concentrates of 65-70 per cent sulfur content.

^j Estimated by senior author of this chapter.

continual deepening of nearly all the mines, with the consequent increase in costs of mining; (4) exhaustion of ore, inundations, and fires in several mines; (5) laws restricting the granting of sulfur-mining concessions (in 1910); (6) labor shortage and the consequent high cost of labor, due formerly to emigration and later to the First World War.

Sicily. The minable sulfur deposits of Sicily are located between Gibellina (Province of Trapani) on the west and Centuripe (Province of Catania) near Mount Etna on the east. They extend as far as the coast near Girgenti in a southerly direction and the most important deposits center about Caltanissetta. The greatest length of the whole district is 99 to 105 miles and the greatest width is 53 to 56 miles. Production techniques are crude and wasteful. Tonnage was reduced to a trifling figure by the war. Improvement since the close of the war has resulted in opening the shafts employed in mining and a larger tonnage has been made available for European markets.

Japan. Japan has been an important producer of sulfur and at times has had an exportable surplus due in part to a large domestic production of pyrite. The Japanese deposits are of volcanic origin and occur as sulfur-bearing clays or as sulfur-bearing muds, ejected during periods of volcanic activity. The most important deposits are in Hokkaido.

As shown in Table 4 the *United States* is producing over 90 per cent of the world's sulfur, and production other than in Italy and Japan does not attain a large figure.

PYRITE

Pyrite is the only sulfide mined directly and intentionally for the production of sulfur.

Composition. Pyrite, iron pyrites or "fool's gold," consists of iron sulfide, FeS_2 : Fe, 46.7 per cent; S, 53.3 per cent. It often contains small amounts of copper, arsenic, nickel, cobalt, or gold.

General Description. Pyrite is a brass-colored mineral usually found in crystals or crystalline masses. The crystals may be cubic, octahedral, pyritohedral, or other isometric forms. It also occurs as massive, disseminated, granular, stalactitic, botryoidal, and so on. It is often found in bituminous coal and known as "coal brasses." *Marcasite* has the same composition and nearly the same properties, but crystallizes in the orthorhombic system, often with radial structure.

Physical Properties. *Hardness*, 6 to 6.5. *Specific gravity*, 4.9 to 5.2. *Melting point*, upon heating it breaks up, liberating sulfur. *Color*, pale brass to golden yellow. *Streak*, greenish to brownish black. *Luster*, metallic. *Cleavage*, none. *Fracture*, uneven. *Transparency*, opaque. *Tenacity*, brittle.

Occurrence. Pyrite is the commonest sulfide mineral and it is widely distributed. It is found in a great variety of ways and often occurs in large quantities. It is mined in many countries and nearly all countries contain pyrite in some form, although not always of commercial interest. Pyrite occurs abundantly in veins or as disseminated crystals or nodules, but the deposits of chief economic importance usually occur as lenticular masses of great size in crystalline or sedimentary rocks of all ages.

The largest pyrite deposits in the world are in Spain and Portugal and these two countries together produce nearly three-quarters of the world's requirements. Other large producing countries have been Norway, the United States, Italy, France, Germany, Canada, Greece, Japan and Hungary. The following countries have also produced pyrite commercially: United Kingdom, Union of South Africa, Australia, Belgium, Bosnia and Herzegovina, Sweden, Algeria, Peru, Cuba, Russia, Austria, Armenia, Serbia, and Finland.

Spain and Portugal. The pyrite deposits of Spain and Portugal occupy a belt about 100 miles long by 12 to 18 miles wide, extending from Anzalcollar in Sevilla through Huelva in Spain to Aljustrel in Alemtejo in Portugal. These deposits have been estimated to contain about 1,000 million tons of pyrite ore. The

TABLE 5. PYRITES (ORES AND CONCENTRATES) PRODUCED IN THE UNITED STATES, 1944 TO 1948

Year	Quantity		Value
	Gross weight, long tons	Sulfur content, per cent	
1944	788,530	42.2	\$2,598,000
1945	722,596	41.0	2,700,000
1946	813,372	41.5	3,228,000
1947	940,652	41.7	4,070,000
1948	928,531	41.8	3,950,000

annual production from this area before the war was nearly 4 million tons, of which about 400,000 tons came from Portugal and the remainder from Spain. Most of the output was exported to the United States, Germany, England, France, and Belgium. The largest and best known lens is the San Dionisio lode of Rio Tinto, Spain, which has a length of $4\frac{1}{2}$ miles and a maximum thickness of about 800 ft. Much of the ore contains copper, for which it was originally worked, and which is still extracted commercially. The sulfur content of the ore ranges from 44 to 52 per cent and averages

about 48 per cent. Both lump ore and fines are shipped.

Norway. Most of the Norwegian pyrite occurs in lenses varying from a few feet up to 60 ft in thickness and often carrying copper. Ores containing 4 to 8 per cent copper are smelted locally; ore lower than 4 per cent copper and containing about 45 per cent sulfur are exported. The most important deposits are situated at Sulitjelma near Salten in Nordland.

Japan. Large reserves of pyrite are known to exist in Japan, and the country generally ranks second to Spain as a producer. The largest deposits are on Honshu and Shikoku. Production of up to 2 million metric tons per year is considered normal. The mineral is used in the manufacture of sulfuric acid, most of which is consumed in the fertilizer industry. Two mines produce about one-half the national total. These are equipped with modern methods of mining and preparation. Many small operations are conducted with hand labor.

United States. Pyrite is produced in California, Montana, New York, Pennsylvania, Tennessee, Virginia, and Wisconsin. Tennessee is the most important producer. The output is converted to sulfuric acid and iron sinter. Pyrite in the form of coal brass is recovered from coal mines in Illinois and Indiana.

World production in 1946 was estimated to total 7 million metric tons. The United States was the leading producer, 826,427 tons, followed by Spain, Norway,

Japan, Italy, Portugal, Cyprus, and France. Small production was scattered in many other countries.

Price. Imported pyrite was quoted in 1950 per long ton, cif United States ports at 14 to 16 cents per unit for material running 48 per cent sulfur, or about \$7 per long ton.

Table 5 illustrates the magnitude of the pyrite industry in the United States.

OTHER SOURCES OF SULFUR

The recovery of sulfur compounds from flue gases is a necessity in areas where such gases are objectionable to industry or humanity. In addition, the conversion of sulfur to sulfuric acid provides a marketable commodity with a reasonable dollar return. The recovery of by-product sulfuric acid from smelters treating copper, lead, and zinc ores is a prolific source of this primary agent. Since smelters tend to be located close to the ore they are located frequently in western areas remote from acid markets. Complete recovery of sulfur cannot be practised due to lack of a market within shipping radius of production.

The amount of sulfuric acid recovered in recent years from nonferrous smelting appears in Table 6.

TABLE 6. BY-PRODUCT SULFURIC ACID EXPRESSED AS 60°BÉ PRODUCED AT COPPER, ZINC, AND LEAD PLANTS IN THE UNITED STATES, 1942 TO 1946, SHORT TONS

	1942	1943	1944	1945	1946
Copper plants*.....	265,522	348,832	320,572	298,309	221,047
Zinc plants.....	695,242	879,266	839,451	786,582	701,080
	960,764	1,228,098	1,160,023	1,084,891	922,127

* Includes sulfuric acid produced as by-product at a lead smelter.

The recovery of coal brasses from coal mines located in Indiana and Illinois has been mentioned. This source will increase in importance due to the growing scarcity of low-sulfur coals and the necessity of cleaning coal for its improvement alone. Some elemental sulfur is now recovered from industrial gases, such as is produced by coke ovens and oil refineries. In 1946, 10 recovery plants were reported to be in operation in the United States, producing over 30,000 tons of sulfur. Sulfur is also recovered from fuel gases, to their improvement for many uses, as hydrogen sulfide. This can be converted to sulfuric acid or burned as a fuel. Sulfur exists in the form of calcium sulfate in untold millions of tons in the minerals anhydrite and gypsum. These minerals have been employed as a source of sulfur, particularly in the manufacture of ammonium sulfate, in England and Germany. They have not been so used in the United States as yet. Because of their widespread occurrence in the United States in great tonnage they supply a potential reserve of primary importance.

Crude petroleum and natural gas are very large potential sources of sulfur. In this country petroleum crudes contain from nearly 0 to over 5 per cent sulfur.

During the past 30 years or more the percentage of total oil production containing 0.5 per cent or more sulfur has ranged from 30 to 44 per cent. High-sulfur or sour-crude production has tended to increase faster than that of low-sulfur crudes. Natural gas containing relatively large percentages of sulfur is abundant. The removal of sulfur from these sources is becoming of increasing importance both to improve the products and as basic sources of sulfur. One or more of the large sulfur-producing companies is planning the production of sulfur from such sources as a hedge against the future exhaustion of economically workable deposits of native sulfur in the Gulf Coast area.

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TALC (STEATITE)

Composition. Talc is a hydrous magnesium silicate, $\text{H}_2\text{Mg}_3(\text{SiO}_3)_4 \cdot \text{SiO}_2$, 63.50 per cent; MgO , 31.70 per cent; H_2O , 4.80 per cent. Most talcs mined commercially contain more or fewer of such impurities as quartz, calcite, dolomite, magnesite tremolite, and iron oxide.

General Description. Talc usually occurs in soft, foliated or compact, massive aggregates, white, gray, or green in color; less often it occurs in apple-green platy, crystalline aggregates; sometimes micaceous or fibrous.

Physical Properties. *Hardness*, 1 to 3.5. *Specific gravity*, 2.6 to 2.8. *Melting point*, 6 in scale of fusibility, or about Seger cone 17 or 18. *Index of refraction*, 1.539 to 1.589. *Color*, pure white, silvery white, gray, various shades of green, to nearly black; also yellow, brown, or reddish when impure. *Streak*, white. *Luster*, greasy to pearly. *Cleavage*, in crystalline varieties, micaceous. *Fracture*, in massive varieties, irregular. *Transparency*, translucent to opaque. *Tenacity*, sectile to nearly brittle. *Feel*, greasy.

Varieties. The most common variety, commercially, is the massive, either foliated or granular, type.

Soapstone is a rock usually containing more or less talc (see page 484).

Steatite was originally an alternative mineralogical name, often restricted to massive talc. In recent years the term has come to mean a high-grade talc suitable for making either block "lava" (see below) or ceramic bodies used for high-grade electrical insulators (see also under Utilization and Ref. 1).

Rensselaerite is a mineral name once applied to a hard, fibrous, waxlike mineral supposed to have the same chemical composition as talc but lacking its softness and its peculiar greasy feel. New York fibrous talc was supposed to consist largely of rensselaerite, but it is generally conceded today that the hard fibers in New York talc are tremolite and not a special variety of talc.

French chalk is a soft, compact variety that will mark cloth.

Pyrophyllite is a hydrous aluminum silicate, closely resembling talc, that is mined, sold, and used commercially as talc for many purposes (see page 415).

Asbestine is a trade name applied to New York fibrous talc.

Agalite, talclay, talcose, verdolite, mineral pulp, etc., are trade names applied to various types of talc.

Lava is a trade name applied to baked talc used for gas-burner tips, electrical insulation, etc. (see under Utilization, page 543).

Occurrence. Talc is usually a secondary mineral resulting from the alteration of other magnesium-containing silicates or, occasionally, carbonates. The original rocks may have been either sedimentary or igneous, types of each being common. Serpentine, tremolite, pyroxenite, and many other rocks have been recognized as constituting the original sources of talcs. In many deposits the alteration is not complete and the talc, as mined and ground, often contains some of these original constituents. Many talc deposits are in the form of irregular, more or less lenticular bodies.

Deposits of talc are rather widely distributed over the earth and are found, to a greater or lesser extent, in nearly every country. Commercial development has been confined mostly to the countries having the greatest industrial development. It has been roughly estimated that just prior to the Second World War the United States produced about 42 per cent of the world's output; Manchuria, 17 per cent; France, 11 per cent; Italy, 13 per cent; Norway, 6 per cent; India, 5 per cent; and Canada, 3 per cent.

United States. It is unfortunate that since 1931 United States production statistics for talc, pyrophyllite, and ground soapstone have been combined so that it is not easy to get a clear picture of the relative importance of talc production from individual states. Total production for these three items has about doubled in the past 20 years, and much of the great increase has come since the start of the Second World War—in part from increased production from former producers and in part from new or reopened mines. This has greatly changed the pattern of domestic production. New York is by far the largest producer of talc. North Carolina, second in the U.S. Bureau of Mines statistical table, produces mainly pyrophyllite with a very small production of true talc. California is the second largest talc producer; Vermont, third; Georgia, fourth. Other states producing a few thousands tons each are Nevada, Washington, Montana, and Texas. Pennsylvania produces a small tonnage of low-grade talc. Maryland and Virginia produce mainly ground soapstone.

*New York.*⁴ For a great many years New York either has been the leading talc producer or has stood second. As recently as 1943 it sold over twice as much as its nearest competitor (California), but that percentage lead has since been cut down by great increases in other states. Most of the New York production comes from St. Lawrence County in an area near Gouverneur. Here is produced a fibrous, tremolitic talc of clear, brilliant white color, used chiefly in the paint and ceramic industries. Less important deposits of granular talc occur near Natural Bridge in Jefferson County.

California. From very small beginnings during the First World War the production of talc in California has risen very rapidly, putting the state in second

place during the past few years. Many excellent deposits are known of all types of foliated, fibrous, and massive talcs suitable for every talc use. Most of the steatite grade of talc for war use came from deposits in Inyo County. Although the bulk of present production comes from deposits in Inyo County (near Keeler, Darwin, Death Valley, and Tecopa) and San Bernardino County (Barstow and Baker), many deposits are known and some are being worked in other counties.

Vermont. At one time the largest producing state, Vermont has its most important working deposits near Johnson, Waterbury, Chester, and Windham. Vermont talcs are of the foliated and granular types—not at all like the New York fibrous talcs in appearance, physical properties, or uses. Talc crayons as well as ground talc are made at Waterbury.

Georgia. The most important talc-producing center in Georgia is Chatsworth, Murray County, where both ground talc and crayons are produced. Other producing deposits in recent years are near Jasper, Pickens County, and Dawsonville, Dawson County. Most of the Georgia talc is of the foliated type with a good slip.

Other states which have shipped appreciable tonnages of talc in recent years are as follows: Washington, from near Marblemount and Clear Lake, Skagit County; Nevada, Esmeralda County; Montana, near Ennis, Madison County; New Mexico, Dona Ana County; North Carolina, Murphy, Cherokee County, and Nantahala, Swain County; Alabama, near Winterboro, Talladega County; Texas, Gillespie County. Relatively small production from Maryland, Virginia, and Pennsylvania has been chiefly low grade talc or ground soapstone. An important exception, perhaps, is the massive lava- and pencil-grade talc from Harford and Cecil Counties, Md. The pyrophyllite production of North Carolina is noted under Pyrophyllite.

Canada. Canada's production of high-grade white talc all comes from near Madoc, Hastings County, Ontario. This talc is whiter than most of the talcs from the eastern United States and usually commands a little better price where this quality is important. Deposits in Quebec, mainly in the Thetford Mines area and at Highwater near the Vermont line, produce soapstone refractory blocks, crayons, and off-color ground soapstone for roofing and other low-grade uses. Massive, steatite-type talc from Red Earth Creek in Kootenay Park, British Columbia, was tested during the Second World War for insulator use but was found unsuitable.

China. Prior to Pearl Harbor, Manchuria reported the second largest world production of talc, over 111,000 tons being exported in 1937—probably mostly to Japan, since little reached this country. At least some of this was of high quality, suitable for toilet uses, but little has been published as to the nature or the extent of the deposits. It is reported that most of the production has come from southern Manchuria, one of the largest mines being in Fengtien at Talin near the Tashichiao station on the P. M. Railway. In China proper deposits are reported to have been operated in Chekiang, Fukien, Shantung, Kweichow, and Shensi provinces.

Germany. Important talc deposits occur in Germany, particularly in Bavaria, at Göpfersgrün near Wunsiedel in the Fichtelgebirge. Most of the German talc seems to be of industrial grade, but excellent lava-grade talc is also produced.

Italy. The highest grade talcs in the world are mined in Italy. Their superior color, freedom from grit and impurities, and fineness of grain make them especially suited for toilet and medicinal uses and for lava blanks. The main producing district is in the Italian Alps in the neighborhood of Perosa, south of Turin in the Valle di Chisone. Talc is mined also near Pinerolo and in the valleys of San Martino, Susa, and Lanzo.

France. France is an important producer of toilet and lava grades of talc. Most of the output comes from deposits in the Department of Ariège, but other important deposits are at Montferrier in the Pyrenees, at Luzech, and at Luzenac near the port of Cette. French, or tailor's, chalk is produced mainly in the Department of Gard, near the port of Toulon.

Other countries which have reported production in recent years of over 1,000 tons per year are Egypt, Greece, British India (important wartime source of steatite talc), French Morocco, Norway, Rumania, Spain, Sweden, Transvaal (Union of South Africa), and Uruguay.

Production and Consumption. *World Production.* Table 1 is taken from the "Minerals Yearbook," 1946 (U.S. Bureau of Mines).

United States production (sales) of talc, pyrophyllite, and ground soapstone in recent years is shown in Table 2, compiled from statistics published by the U.S. Bureau of Mines.

Prewar imports reached a peak of nearly 27,000 tons in 1937. Most of this was ground talc, chiefly from Canada, Italy, France, and China, crude imports amounting to only 324 tons. In the same year our exports were around 9,000 tons, leaving a net balance for domestic consumption of about 18,000 tons. During the war imports dropped to a minimum of about 6,600 tons in 1943 and had not increased by 1945. During the war years and in 1945 our exports averaged about 11,000 tons per year. Thus, in 1945 there was a net loss to domestic consumption of around 5,000 tons. In 1946 exports rose to about 16,000 tons and imports to about 18,000 tons.

The marketed 1946 production total of over 457,000 tons (which included about 96,500 tons of pyrophyllite) was by far the largest on record. Since our imports and exports are nearly in balance this must represent close to our domestic consumption.

Mining and Milling. Nearly all the talc produced is obtained by underground mining methods, but the methods used vary greatly in different districts. Many, perhaps most, talc deposits are irregular in shape and extent, and in many cases little attention has been given to the development of systematic mining methods. In a few instances, notably at the Henderson mine at Madoc, Ontario, Canada, a definite and efficient system has been evolved. This mine is opened by vertical shafts in the foot wall and the ore is extracted by a method of shrinkage stoping.

In Vermont and New York most of the mines are opened by inclined shafts in the vein. From the shafts, levels are driven in each direction along the vein at vertical intervals ranging from 50 to 200 ft. Where the vein is not over 15 or 20 ft wide, the drifts may be cut the full width of the vein. If the veins are wider than 20 ft, several such wide drifts may be cut and frequent connections made between them, thus resulting in a sort of room-and-pillar method. Raises are

TABLE 1. WORLD PRODUCTION OF TALC, PYROPHYLLITE, AND SOAPSTONE, 1940 TO 1946, BY COUNTRIES, METRIC TONS^a
(Compiled by P. Roberts)

Country ^a	1940	1941	1942	1943	1944	1945	1946
Argentina.....	1,168	1,975	4,770	3,557	3,421	b	b
Australia:							
New South Wales...	754	1,153	1,454	1,814	1,874	1,776	b
South Australia.....	1,349	2,972	2,577	3,336	3,930	3,037	3,727
Tasmania.....	.....	.....	.....	.....	4	155	50
Western Australia..	.....	.....	308	74	266	b	396
Austria.....	26,913	35,956	42,933	57,639	44,628	4,470	21,429
Canada.....	21,583	31,417	27,096	23,735	29,571	24,574	29,167
Chile.....	b	b	b	276	935	477	b
China.....	73,000	76,000	80,000	b	b	b	b
Egypt.....	2,212	5,229	1,875	2,054	4,265	3,868	4,760
Finland.....	b	b	b	b	b	75	b
France.....	b	b	50,150	48,300	26,720	42,461	66,477
Germany.....	9,449	12,170	13,526	b	b	b	b
India.....	30,186	26,571	32,262	16,700	21,735	22,704	b
Indochina, French....	305	370	260	360	530	b	b
Italy.....	71,443	73,475	80,462	b	b	46,287	b
Japan.....	.....	.....	.....	.....	.....	.....	200
Kenya.....	b	b	b	b	123	67	b
Korea (Chosen).....	60,227	b	b	b	50,226	b	b
Madagascar.....	b	c	c	39	c	b	b
Morocco, French.....	b	b	b	b	b	b	b
Newfoundland.....	284	508	1,580	2,439	224	711	660
New Zealand.....	b	b	15	63	25	b	b
Norway.....	17,028	29,059	30,174	30,454	b	b	b
Rumania.....	1,556	3,347	3,052	1,609	b	b	b
Spain ^d	28,643	29,148	36,497	14,238	10,470	19,319	b
Sweden.....	7,569	5,233	6,153	5,335	5,512	7,806	b
Tanganyika.....	6	b	b	b	b	b	b
Union of South Africa.	1,671	2,458	1,985	5,344	2,875	1,947	2,609
United Kingdom.....	1,074	4,532	2,231	2,815	2,829	b	b
United States ^e	255,258	377,722	351,952	374,456	361,841	361,406	414,641
Uruguay.....	1,699 ^f	2,111	4,588	1,985	2,257	1,823	1,818
Total ^g	664,000	822,000	826,000	747,000	706,000	690,000	770,000

^a In addition to countries listed, talc or pyrophyllite is reported produced in Brazil, Bulgaria, Greece, and U.S.S.R., but data on production are not available.

^b Data not available.

^c Less than 1 ton.

^d Includes steatite, as follows—1940: 17,191; 1941: 18,948; 1942: 24,859; 1943: 9,741; 1944: 7,369; 1945: 15,577.

^e Talc, pyrophyllite, and ground soapstone sold by producers; includes also pinitite in 1940 to 1942 and 1944.

^f Exports.

^g Excludes estimates for countries listed in footnote ^a.

TABLE 2. TALC, PYROPHYLLITE, AND GROUND SOAPSTONE SOLD BY PRODUCERS IN THE UNITED STATES, BY STATES

State	1937		1938		1941		1942		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
California.....	32,495	\$ 427,031	30,059	\$ 391,456	59,203	\$ 811,793	51,649	\$ 678,006	67,321	\$1,254,143	78,170	\$1,434,978
Georgia.....	11,984	148,177	15,117	130,595	28,511	364,560	29,930	464,160	32,433	296,163	36,410	380,477
Maryland, Pennsylvania, and Virginia	19,606	108,470	18,416	99,170	^a	^a	^b	^b	34,084	329,631	42,505	424,334
Nevada ^c	0	0	0	0	13,178	126,433	12,339	236,033	11,780	185,059	7,589	141,180
New York.....	96,140	1,215,834	86,423	1,110,024	153,560	1,917,732	136,752	1,886,678	^d	^d	^d	^d
North Carolina ^d	28,250	271,013	27,460	241,337	64,783	567,921	56,909	503,082	78,369	682,510	87,718	976,524
Vermont.....	41,118	384,474	35,126	329,084	57,248	663,268	58,695	659,314	63,574	752,583	75,144	843,247
Washington.....	406	6,754	174	894	6	2,426	7	2,864	2,804	33,458	5,084	38,051
Other states ^e.....	.....	.....	.....	.....	29,252	142,196	26,388	178,332	108,019	1,873,688	124,446	2,206,553
Total ^f	299,999	\$2,561,753	212,775	\$2,302,560	416,369	\$4,701,892	387,963	\$4,754,076	398,384	\$5,407,235	457,066	\$6,445,344

^a Maryland 15,628 tons, valued at \$105,363; Pennsylvania and Virginia included in Other states.^b Maryland 15,294 tons valued at \$144,707; Pennsylvania and Virginia included in Other states.^c Includes pinites, 1941, 1942, 1944.^d Included under Other states.^e Includes pyrophyllite whose tonnage could not be revealed separately prior to 1942. Pyrophyllite production: 1942, 53,669 tons valued at \$414,816; chiefly from North Carolina; 1945, 77,594 tons valued at \$651,200; 1946, 96,551 tons valued at \$998,303.^f 1941, Montana, Pennsylvania, Virginia. 1942, Alabama, Montana, New Mexico, Pennsylvania. 1945, Montana, New Mexico, New York, Texas. 1946, Montana, New York, Texas.

put up at more or less regular intervals, at such an angle that the broken ore will run to the level below. These raises may be cut as large as 20 ft square and are often connected at the top. Thus, as much of the ore as possible is recovered in large development openings. When the limits of the ore body are reached on a given level, part of the pillars may be recovered, but enough ore or waste is left standing in pillars to hold the walls. Then the shaft is deepened and another level is started. When the ore body has been worked out by this method, the pillars farthest from the shaft on each level are mined out and as much ore as possible is recovered, retreating toward the shaft from both directions, until the walls cave so badly that the mine must be abandoned. Little timber is used in mining. Drilling is usually easy and is commonly done with light compressed-air hammer drills of the jackhammer type or with stoping drills.

In small mines in the southern states mining is usually unsystematic, and much of the ore is recovered in development openings.

Prior to the development of the first commercial froth flotation of talc by the Eastern Magnesia Talc Co. at Johnson, Vt., in 1937, little had been done to beneficiate talc. Such improvement in quality as had been achieved was done by hand selection of ore, screening, "throwout" devices to remove coarse impurities, and partial division into quality factions by air separation. Wet grinding and froth flotation enabled the separation of pure talc from its associated minerals, and this necessitated detailed mineralogical studies of the crude talcs. In some cases, it was found that some of the accessory minerals could probably be recovered as salable commercial products. Thus, at Johnson, Vt., the ore contains magnesite [var. bruennnerite (MgFeCO_3)] and nickel [in the minerals pyrrhotite (FeS) and gersdorffite (NiAsS)]. While, to date, the only flotation plant in operation in the industry is that at Johnson, the means are now available for making relatively pure talc products from impure ores.

Dry-milling methods in use today vary more in detail and in size than in fundamental principles. The crude ore is reduced in jaw crushers followed by rolls or rotary crushers. Dry, mined rock is usually kept separate from wet fines, and the latter are dried in rotary driers. The dry or dried ore is then ground in Raymond roller mills with whizzer air separators or Hardinge conical pebble mills, followed by Raymond or Gay Co. air separators. The finished products are binned and packed in 100-lb paper bags. Coarse, granular products for roofing are made by screening air-separator tailings on vibrating screens. When making the finer grades or grinding hard ones (such as New York fibrous talc) Raymond or pebble mills in tandem may be used with a double air separation (reseparation of tailings from first separation). The finest grades (99.98 per cent through 325 mesh) come from secondary stocking collectors on air separators or are made in micronizers.

The abbreviated flow sheets* (Figs. 15 to 18) illustrate the general methods used in the industries.

In the flotation plant flow sheet† (Fig. 16) the nickel concentrate (with about

* Courtesy of Joseph M. Smith, Pres., Eastern Magnesia Talc Co., Burlington, Vt.

† For a detailed description of this plant see *Deco Trefoil*, Denver Equipment Co., Denver, Colo., February, 1940, pp. 5-8.

TALC (STEATITE)

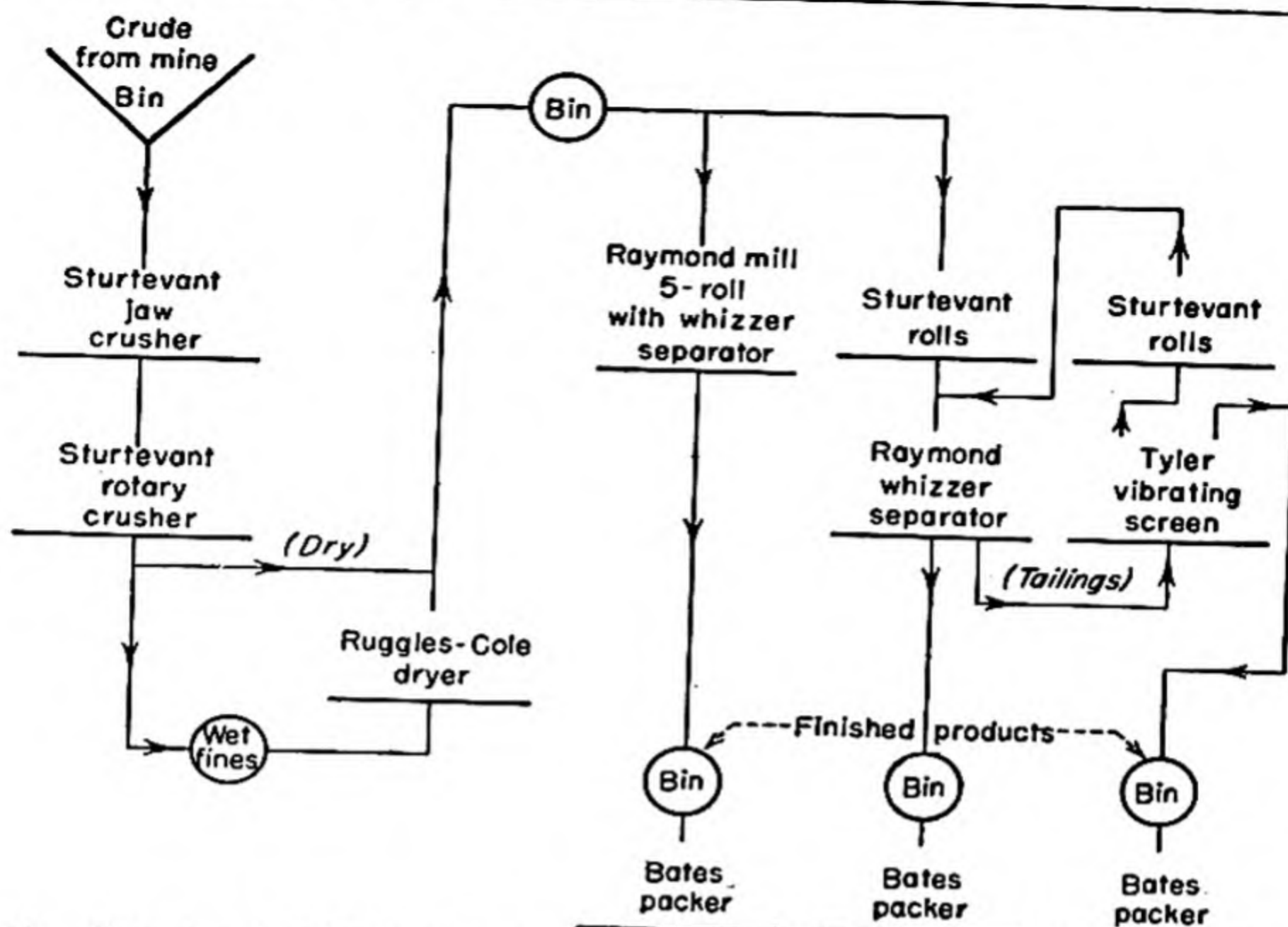


FIG. 15. Flow sheet of Eastern Magnesia Talc Co., Inc., Mill No. 2, Waterbury, Vt.

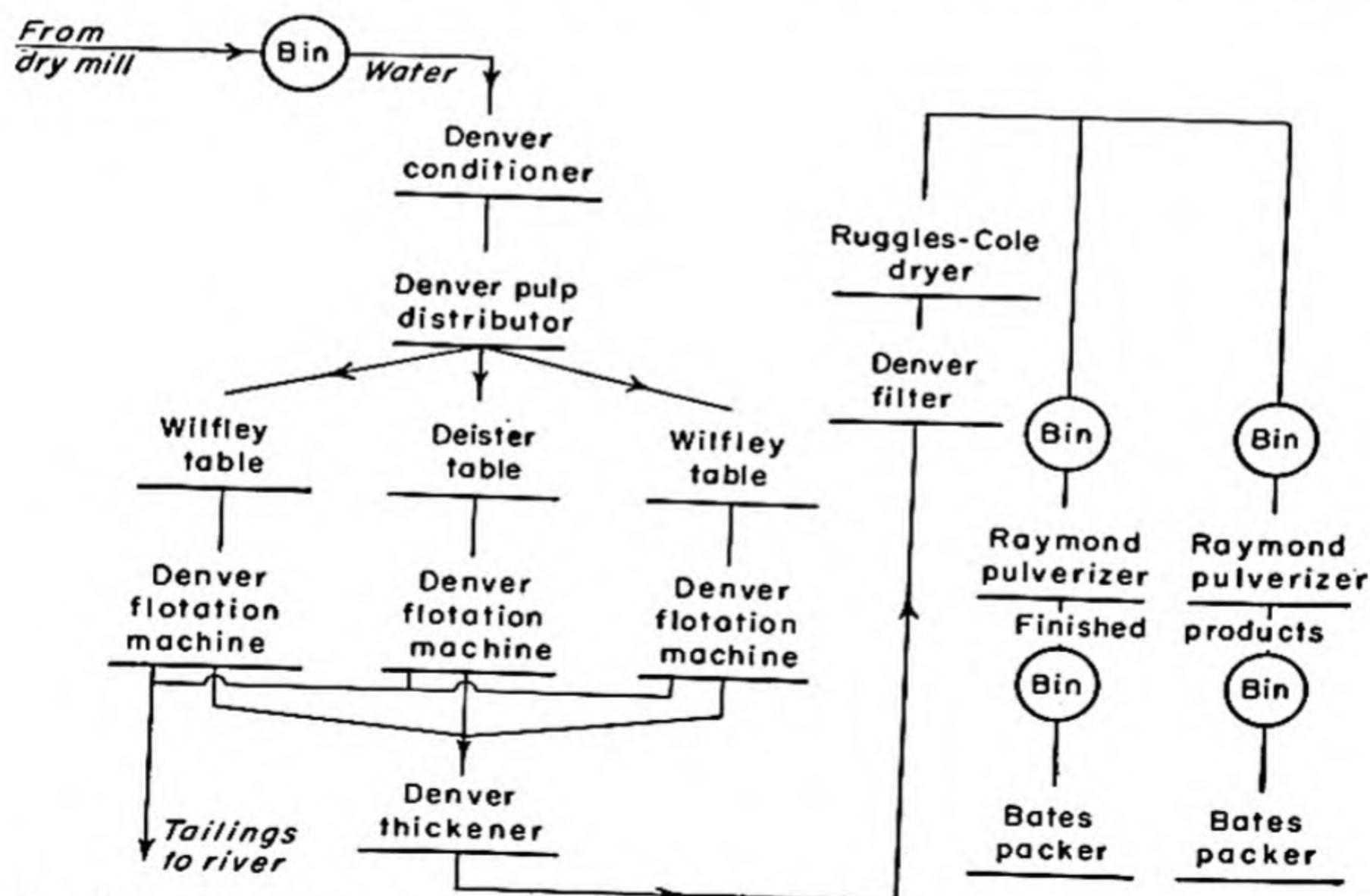


FIG. 16. Flow sheet of Eastern Magnesia Talc Co., Inc., Mill No. 4, flotation plant, Johnson, Vt.

TALC (STEATITE)

that will make a mark on hot or cold metal which is visible when reheated or cooled.

Crayons are made in several sizes, for example, 5 by $\frac{1}{4}$ by $\frac{1}{4}$ in., 5 by $1\frac{1}{4}$ by $\frac{3}{16}$ in., 5 by $\frac{1}{2}$ by $\frac{3}{16}$ in., and so on, but the most common size is probably 5 by $\frac{1}{2}$ by $\frac{3}{16}$ in.

Crayons are made from selected stock, of medium-hard, massive compact talc. The grain of the talc should run lengthwise of the crayon in order to increase its strength. All the sawing is done with circular saws resembling ordinary circular

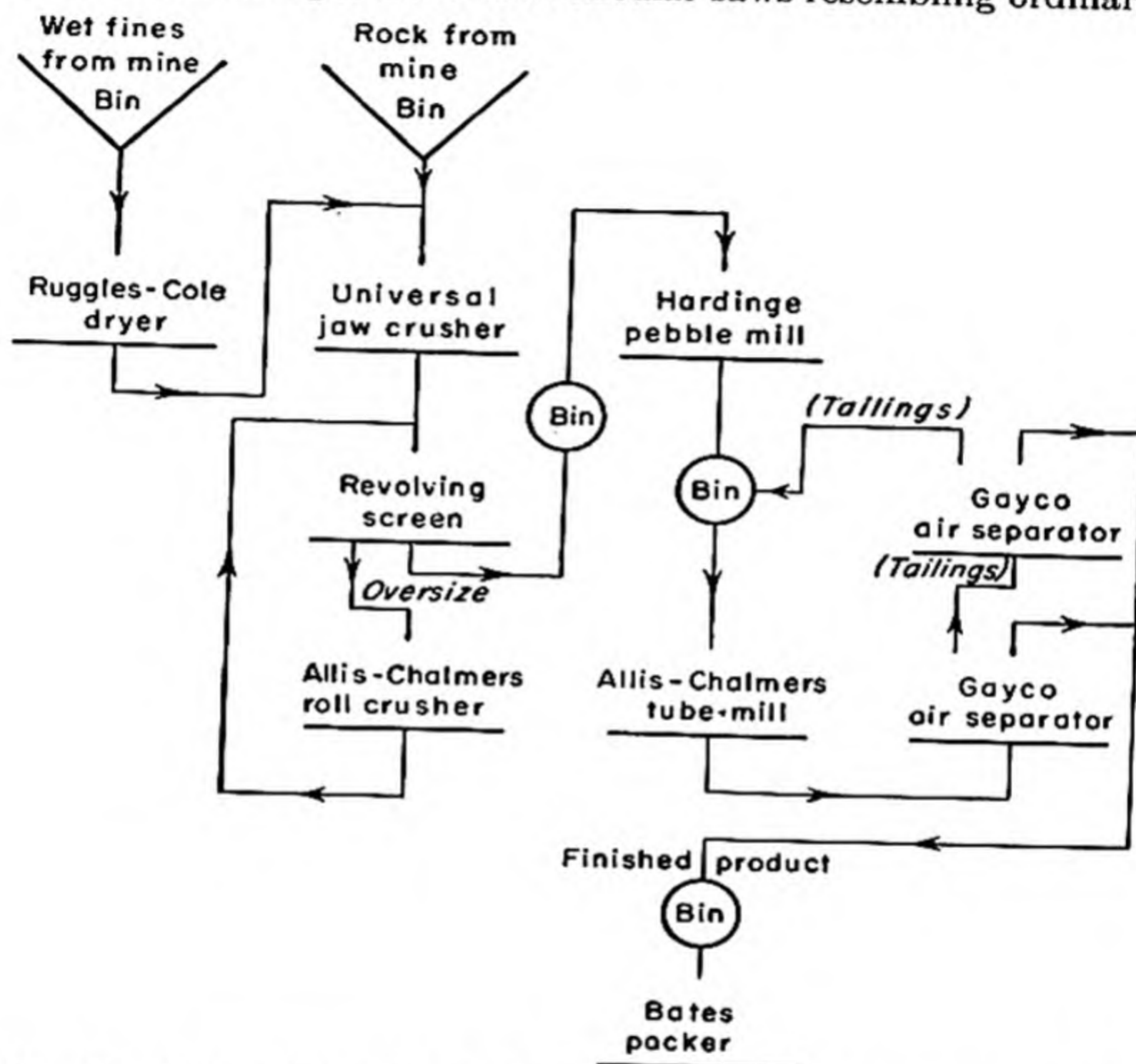


FIG. 18. Flow sheet of W. H. Loomis Talc Corp., Gouverneur, N.Y.

saws used in wood working. The blocks of crude talc are first squared up with large saws (18 to 24 in. in diameter). Next, these blocks are sawed into thin slabs of a thickness equal to the width of the crayons to be made. The thin slabs are then further subdivided with smaller saws (6 to 12 in. in diameter) to the final sizes desired, and the crayons sorted and packed in small wooden boxes for shipment.

Marketing and Shipping. Talc is marketed chiefly as a finely ground powder, 180 mesh or finer; but considerable talc of coarser sizes, for example, through 40 on 60 mesh or through 30 on 80 mesh, is sold for use as a surfacing material for prepared asphalt-felt roofing. Massive talc is marketed in the form of metal workers' crayons and tailor's chalk and as blanks for the manufacture of Lava gas-burner tips and so on.

The largest markets for talc are in the great industrial districts east of the Mississippi, north of Virginia and Kentucky, and in California. Most talc in carlots is sold directly by the producer to the consumer, but less-than-carlot business is often handled by brokers and jobbers.

The coarser grades of talc may be shipped in bulk in paper-lined boxcars, but most of the 200-mesh and finer talc is packed in 50-lb paper bags or 200-lb burlap bags, though other containers are sometimes used.

Prices. Prices are generally quoted on the short-ton basis, fob cars grinding mill, and vary according to the type of talc, fineness of grinding, and purity. In general, due to keen competition, prices of domestic talc have been relatively low, with the possible exception of New York fibrous talc. In some cases certain grades of talc have been sold below the cost of production in an effort to market a surplus of a highly competitive product.

In early 1950 prices quoted by the *Engineering and Mining Journal, Metal and Mineral Markets*, were as follows:

Georgia: 98 per cent through 200 mesh, \$10; white, \$12.50 to \$15.00, packed in paper bags

New Jersey: Mineral pulp, ground, \$10.50 to \$12.50, bags extra

New York: Double air-floated, short fiber, 325 mesh, \$18.50 to \$20.00

Vermont: 100 per cent through 200 mesh, extra white, bulk basis, \$12.50; 99½ per cent through 200 mesh, medium white, \$11.50 to \$12.50; packed in paper bags, \$1.75 per ton extra

Specifications and Tests. Although there are no general over-all specifications for talc, most of the important consuming industries today are very exacting in their requirements and have their own tests and specifications. Some of the larger and more alert talc producers today have very able research and control laboratories and publish detailed data on the physical and chemical properties of their products,* while the less advanced producers still rely almost entirely on customers' evaluation of their talcs.

Since talcs vary so widely in their properties and since use requirements in each industry are so dissimilar, many types of tests and analyses must be made. The Sierra Talc and Clay Co. of Los Angeles, Calif., produces several types of talc (foliated, fibrous, granular) and many grades and blends based on fineness, chemical analyses, and ceramic and other physical properties. Data supplied as routine cover (1) complete chemical analyses, (2) acid solubles such as CaO, (3) color (brightness), (4) pH value, (5) specific gravity, (6) fineness by screen test and in microns, (7) apparent density, and (8) particle shape and type. In addition, the following data are supplied: for cosmetics, (9) slip rating, and (10) grit residue by decantation; for paint, (11) oil absorption (by two methods), (12) pounds per solid gallon, and (13) bulkage value; for ceramics at seven different firing temperatures, (14) bulk specific gravity, (15) diameter shrinkage, (16) volume shrinkage, (17) absorption, (18) apparent porosity, and (19) apparent specific gravity. Additional data for other uses is also supplied.

A high-grade talc, in general, should be of a pure-white color, low in lime and

* For excellent examples of test data on talcs see data sheets and bulletins of the Sierra Talc and Clay Co., Los Angeles, Calif.

iron, free from grit and specks or impurities, and finely ground (200 mesh or finer). A good "slip" (greasy feel) may or may not be desired. This grade of talc is used mainly by the toilet-powder trade.

Industrial talc usually is not so pure white in color, except New York fibrous talc and some Canadian talcs, as that used for the other purposes noted. It often contains carbonates and sometimes free silica; often it is not finely ground.

The fineness of grinding varies widely and depends upon the use for which the talc is intended and upon the consumer's ideas of his needs. In general, industrial grades of talc are standardized according to the proportion that will pass through a 325-mesh sieve, various specifications requiring from 95 to 99.8 per cent to pass. Roofing-grade talc, if used as a dusting agent, may have a maximum grain size varying from 100 to 140 mesh or even finer. For prepared roofing granules of various grades, such as through 20 mesh on 40 mesh, through 40 on 60, through 40 on 100, through 30 on 80, and so on, are made.

Utilization. Talc is used for a great variety of purposes, at least 60 different uses having been noted; but many of these uses are at present of minor importance. It should be noted that, owing to inherent differences in physical and chemical properties between talcs from different districts, all talcs cannot be used for all purposes. Thus, a foliated talc may be well adapted for paper filler, while a fibrous talc is usually preferred by the paint trade. In testing the adaptability of talcs for new uses, several types of talc should be tried, as well as talcs of several degrees of fineness.

Table 3 shows the estimated distribution of sales of talc, pyrophyllite, and ground soapstone in the United States in 1945 and 1946. From these figures it is

TABLE 3. UNITED STATES SALES BY USES, 1945 TO 1946
Per Cent of Total

Paint.....	23-26
Rubber.....	14-16
Roofing.....	12
Ceramics.....	10-14
Insecticides.....	9-14
Paper.....	7
Toilet preparations.....	4-5
Foundry facings.....	2
Crayons.....	Less than .05
Other uses reported*.....	5-6
Uses not reported.....	5-7

* Textiles, refractories, plaster, plastics, asphalt filler, agriculture, and other minor uses.

evident that today five industries—paint, rubber, roofing, ceramics, and insecticides—consume about 75 per cent of the total United States production. This represents great changes in use pattern in the past 25 years. The paper-industry use has dropped from leading position (38 per cent in 1921) to 7 per cent. Paint-industry use, as far as percentage is concerned, has not changed. Uses in ceramics and insecticides, however, once too small to be noted separately, have become of major importance.

The decline in paper use has been due to the development of better materials at

equal or lower prices. The large and increasing use in ceramics has been due to research, particularly the development of bodies for wall tile, whiteware, and electrical porcelain in which talc is a major constituent. Use in insecticides has been tremendously increased by the large-scale development of DDT dusts in which talc or pyrophyllite is used as an inert carrier or diluent. The important factors here are cheapness, availability, softness and freedom from abrasive grains, and ability to adhere to foliage. Competition is from other cheap fillers such as clay. In paint, talc is used as an inert extender, for which purpose it competes with ground silica, whiting, clay, and other inert, finely ground mineral substances. However, certain types of talc perform special functions for which there are no acceptable substitutes. For example, fibrous talcs have the ability both to stay in suspension in paint vehicles and to hold other pigments in suspension, thus preventing separation and hardening of pigments in the can. Tremolitic fibers in the talc also tend to have an interlocking or bonding effect on the paint film. Foliated talc tends to give a plated structure to a paint film, resembling the action of mica. Pure-white fibrous talcs are also used in cold-water paints where the talc serves as the pigment itself.

As a filler and coating pigment in paper, talc competes chiefly with clay. Its great advantage over clay is its higher retention in the finished paper; its disadvantages have often been poor color, grit content, and coarse grain size (compared to clay).

In the manufacture of prepared asphalt paper roofing, talc is used chiefly as a surfacing material and as a dusting agent to prevent sticking.

In the manufacture of rubber, talc is used chiefly as a dusting agent, but is also used to some extent as a filler in the lower grades of rubber goods.

Some of the other uses for which ground talc is adopted are as follows: as a filler in soap; in foundry facings and wire-insulating compounds; in lubricants; as a filler in linoleum and oilcloth; in gypsum and other wall plasters; in shoe polishes and cleaners; as an absorbent for oils, odors, organic colors, etc.; as a filler in cotton textiles; in the dressing and manufacture of leather; as a cleaning and polishing agent for rice, peas, coffee beans, peanuts, etc.; in making colored crayons; as a filler in window-shade cloth; and as a dusting agent in making candy, chewing gum, etc. The use of massive talc for crayons has already been briefly noted.

An important but, from a tonnage standpoint, a rather minor use for massive talc is in the manufacture of "lava" or massive steatite gas-burner tips and electrical insulation. Lava is a trade name for a hard, dense substance made by baking certain types of talc at a high temperature. For the manufacture of lava, talc must be fine grained, homogeneous, compact, and without cleavage or with very poor cleavage; it should have a low water content and must be free from grit and low in iron. If a talc has these qualities, it must be subjected to cutting and baking tests before its suitability can be entirely established.

Lava is harder than glass; it has a compressive strength of 20,000 to 30,000 psi; it is not affected by heat below 1100°C; it is unaffected by alkalis or acids except hydrochloric, which attacks it but slowly; and its dielectric strength is 75 to 250 volts per one-thousandth in. in thickness.

Lava objects are made from crude talc blanks sawed nearly to size. These blanks are placed in small high-speed lathes, where they are turned, drilled, and threaded; thence to small saws or other tools until the desired form is finally achieved. The objects are then placed in small electric or gas-fired ovens or kilns and subjected to a temperature of about 2000°F (1100°C) for 24 to 48 hr. There is practically no shrinkage in the baking process; consequently, it is possible to manufacture articles in which accuracy of size is important. A great variety of gas-burner tips, small electrical insulating parts, spark plugs, and so on are manufactured.

As the value of lava insulators for high-frequency electrical insulation became more widely appreciated the supply of suitable massive talc became inadequate, and much research was done to develop synthetic lava ceramic bodies from ground talc plus binders. Eventually, successful formulas were developed, but the synthetic products are not quite so good for all purposes as those made from massive talc. All products, both natural and synthetic, have come to be called "steatite" products in the insulator trade. Only talcs of high purity are acceptable for these products. As war demands for steatite insulators for radio, radar, airplane spark-plug shields, and other high-frequency uses reached large proportions, intensive searches were made for talcs suitable for this exacting use. The best material came from the Talc City mine of the Sierra Talc and Clay Co., Inyo County, Calif., and this became the standard for the industry. For steatite ceramics 80 to 90 per cent of ground talc is mixed with about 5 per cent of kaolin binder and a flux such as feldspar or alkaline earths and fired to cone 12 or 14.

Talc ceramic bodies are widely used for floor and wall tile, whiteware, saggers, artware, and porcelain.

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THALLIUM

Composition and General Description. Thallium is a soft metal, bluish in color, resembling lead. It has a specific gravity of 11.8 and a melting point of 302°C ; and it oxidizes readily on exposure. When heated it burns with a green flame. It does not occur free nor are the minerals containing it common. Crookesite, $(\text{CuTlAg})_2\text{Se}$, named for the chemist Crookes, who reported the discovery of the element in 1861, is the best known. It was discovered in the flue dust obtained as a by-product of the calcination of pyrite in the manufacture of sulfuric acid.

Production. Thallium has been reported to occur in the potassium minerals carnallite and sylvite, and in mica, sulfur, and many other minerals. These sources have not been industrially significant. Commercial recovery has been restricted to the flue dust and chamber muds recovered during the calcination of pyrite and sphalerite in sulfuric acid plants. Flue dusts containing up to 0.6 per cent thallium, present as sulfate, have been reported. This material is boiled in dilute sulfuric acid, the associated metals removed by precipitation and filtration, and the thallium precipitated. World production has been estimated at 500 metric tons annually.² In 1948 the metal was quoted at \$15 per pound. Analysis of pyrite from various sources has disclosed the presence of unexpected amounts of thallium, suggesting that the element might be produced in greater quantity and possibly at a lower price as research continues to find new uses for its unusual properties.

Utilization. Compounds of thallium are highly toxic. An important use is in the preparation of rodenticides. The sulfate is commonly used, and since it is odorless and tasteless it is exceptionally effective in rat control. Thallium oxysulfide has shown superior service as a substitute for selenium in photoelectric cells. It possesses higher sensitivity to light of long wavelength and low intensity. Thallium salts have been used as a source of monochromatic light in the green range of the spectrum. Precaution against the poisonous nature of thallium salts must be observed. Perhaps the most interesting use of thallium is in the manufacture of compounds with a high transparency to infrared light. During the war flat, polished, single-crystal plates of TlBr-TlI and TlBr-TlCl were developed in Germany. They were used in photocells employed in infrared signal devices. They are reported to possess excellent durability to the atmosphere and to be the most satisfactory infrared transmitter window known.

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TITANIUM MINERALS

The industrial importance of the titanium minerals has increased with greater rapidity during the last decade than that of any other group of minerals with the exception of uranium with its peculiar association with atomic power. Titanium is a common element in the crust of the earth and is found in varying percentages in many minerals other than those properly considered to be members of the titanium group. Commercial production of titanium compounds is obtained almost entirely from rutile and ilmenite.

RUTILE

Composition. Rutile is one of the trimorphous forms of titanium oxide, TiO_2 : Ti, 60 per cent; O_2 , 40 per cent. The other two forms, having the same composition, are octahedrite (anatase) and brookite. Rutile is the most stable and most common form. A comparison of the common properties of the three minerals is presented in Table 1.

TABLE 1. FORMS OF TITANIUM OXIDE, TiO_2

Mineral	Specific gravity	Crystal system	Index of refraction
Octahedrite (anatase).....	3.84	Tetragonal	2.493-2.554
Brookite.....	4.17	Orthorhombic	2.583-2.741
Rutile.....	4.2-4.3	Tetragonal	2.616-2.903

Rutile (sometimes called *nigrine*) commonly occurs in brownish-red to nearly black, frequently striated, prismatic to thick columnar crystals; also as needle-like crystal inclusions in quartz (rutilated quartz), feldspar, and other minerals; in parallel and netted needles upon hematite or magnetite; in compact or granular masses; and as sand in placer deposits.

Physical Properties. *Hardness*, 6 to 6.5. *Specific gravity*, 4.2 to 4.3. *Melting point*, high. *Index of refraction*, 2.616 to 2.903. *Color*, red-brown, red and black; deep red when transparent. *Streak*, white, yellow, to pale brown. *Luster*, adamantine to almost metallic. *Cleavage*, distinct prismatic and pyramidal. *Transparency*, opaque to transparent. *Tenacity*, brittle. Insoluble in acids and infusible before the blow pipe.

Occurrence. Rutile and ilmenite occur together frequently. This is commonly true in placers where their high specific gravity has caused a mixed concentration of heavy minerals, which is economically important at times because it permits the recovery of more than one valuable mineral from a single operation. This is the case in Florida, where rutile, ilmenite, and zircon are recovered simultaneously, and in Australia, where a similar concentrate is produced and shipped to this country for separation. Rutile has been produced near Piney River, Va., for years and the occurrence has been described in detail.¹⁷ The mineral occurs also in Hot Springs County, Ark., and has been produced in quantity although production has not been recorded since 1944. Small placers are known in western North Carolina, and rutile is known to occur in the black sands of the Pacific coast. Marine placers extending over some 300 miles of the coast of New South Wales and Queensland are believed to form a substantial reserve for future use. International occurrence is shown in Table 4.

Mining and Milling. Mining consists of scraping the titaniferous sands for transport to a concentrating mill. Because of the mineralogical complex involved the separation of the individual minerals requires the use of a number of methods. As described by Vogel²⁶ at an operation in Arkansas, rutile formed about 3 per cent of the mine-run ore. Associated with it were a number of accessory minerals including clay, quartz, novaculite, feldspar, apatite, pyrite, magnetite, hematite, and others. The ore was removed from the pit and crushed and ground. It was then concentrated on tables, after which flotation was used to eliminate certain impurities. The concentrate was then jigged, tabled, and roasted, after which it was subjected to electrostatic separation, producing a concentrate that was cleaned by magnetic separation to produce a shipping product. Humphrey spirals are used in Florida in treating sands for the recovery of rutile, ilmenite, and zircon.

Utilization. Utilization is shown in Table 6. It will be noted that welding-rod coatings is the most important use and in most years consumes over 80 per cent of the total. The Bureau of Mines reports that in 1946, 133,000 short tons of titanium-coated rods were manufactured. Of these, 53 per cent were coated with natural rutile. The rest were coated with manufactured TiO_2 , natural and manufactured TiO_3 , and ilmenite. The next most important use of rutile is in the manufacture of alloys. A small tonnage is employed as a coloring agent in ceramic wares. The price of rutile commonly is between 8 and 10 cents per pound for material containing 94 per cent TiO_2 .

ILMENITE

Composition. Ilmenite (also called *menaccanite* and titanite iron ore) is an oxide of iron and titanium, FeTiO_3 : Ti, 31.6 per cent; Fe, 36.8 per cent; O_2 , 31.6 per cent, or TiO_2 , 52.67 per cent; FeO , 47.33 per cent. Sometimes small amounts of manganese or magnesium may replace part of the iron.

General Description. Ilmenite usually is found in iron-black, compact or granular masses, or in thin platy crystals resembling hematite, also in disseminated grains and as sand or pebbles. Frequently it is associated with magnetite,

and in the past such titaniferous ores were considered worthless since they could not be employed as a source of iron nor could the ilmenite be separated in useful form. The application of modern technology has made it possible to treat such ores, and they have become the most important source of ilmenite. Disintegration of titaniferous rocks has liberated both ilmenite and rutile. Since these minerals are inert and have a high specific gravity they are concentrated readily in placer deposits along stream beds and beaches with other heavy minerals such as magnetite, zircon, and monazite.

Physical Properties. *Hardness*, 5 to 6. *Specific gravity*, 4.3 to 5.5. *Melting point*, high. *Color*, iron black to brownish black. *Streak*, black to brownish red. *Luster*, metallic to submetallic. *Cleavage*, none, but basal and rhombohedral parting. *Fracture*, conchoidal to uneven. *Transparency*, opaque. *Tenacity*, brittle. Slightly *magnetic*, greatly increased by heating.

Occurrence. Ilmenite is one of the most widely distributed minerals and is found in many river beds and beach sands as the result of the disintegration of igneous rocks. The marine sands of Manavalakurichi and Quilon, Travancore, India, are a prolific source and until the development of the titanium industry in the United States after 1940 were the world's largest source. Other countries have recorded small production as shown in Table 4. The ilmenite industry in the United States was small and located in Florida, North Carolina, and Virginia until the opening of operations in New York. Large deposits of titaniferous magnetite were known to occur in the Lake Sanford area in the Adirondack area since 1826. Attempts to use the material as an ore of iron were not successful due to the titanium content. In 1941 the National Lead Co. developed the property, producing an ilmenite concentrate suitable for processing to recover the titanium content and a magnetite concentrate for the iron blast furnace. Production increased rapidly and the significance of imports from India declined. The position of Canada as a producer is expected to change soon. The Allard Lake, Quebec, deposits^{10a} have been taken over by a company controlled by the Kennecott Copper Corp. and the New Jersey Zinc Co. These are reported to contain 125 million tons of ore averaging around 35 per cent TiO_2 . In August, 1948, it was stated that a smelter would be built at Sorel, Quebec, to treat the ore.

In 1949 ilmenite production in the United States came chiefly from the following operations:^{2a}

Virginia. At Piney River³ the Calco Chemical Division of American Cyanamid Co. produces about 170,000 tons of crude ore per year from the nelsonite deposits in which ilmenite is associated with apatite and ferromagnesian minerals. Concentration is in Humphrey spirals and by froth flotation. At Roseland the American Rutile Co. is mining a mixture of ilmenite and rutile from a 6 to 10 per cent disseminated ore body.

Florida. The Humphrey Gold Corp. produces ilmenite, rutile, and zircon from beach sands, near Jacksonville (for the Rutile Mining Co.) and from the Trail Ridge deposit near Starke (for the du Pont Co.). Concentration is by Humphrey spirals and the three valuable minerals are separated in electrostatic separators. These two operations are the largest producers of rutile and zircon in the United States and the second largest producer of ilmenite.

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North Carolina. Near the headwaters of the Yadkin River, about 16 miles north of Lenoir, Caldwell County, the Yadkin Mica & Ilmenite Co. (subsidiary of the Glidden Co.) mines an ilmenite-chlorite schist from an ore body 20 ft thick that extends for at least 2,000 ft in length and 500 ft in depth. The ore averages 50 per cent ilmenite and 40 per cent chlorite with a minor rutile content. The ore is ground to 150 mesh in a Hardinge rod mill and the ilmenite separated by simple washing and scrubbing. Production is about 30,000 tons of 52 per cent TiO_2 ilmenite per year.

New York. The MacIntyre property^{10,15,21} of the National Lead Co., located at Tahawus in the Sanford Lake area of Essex County, consists of a mixture of magnetite and ilmenite in two tabular masses 2,000 ft long and of variable thickness up to several hundred feet. The ore, averaging 16 per cent TiO_2 and 34 per cent iron, is mined by open-pit methods. Concentration is by magnetic separation followed by flotation. In 1948 this property produced about 250,000 tons of ilmenite and 500,000 tons of magnetite containing about 57 per cent iron.

Production and Consumption. Production and consumption of titanium minerals in the United States for recent years are shown in Tables 2 and 3.

TABLE 2. PRODUCTION AND MINE SHIPMENTS OF TITANIUM CONCENTRATES FROM DOMESTIC ORES IN THE UNITED STATES, 1942 TO 1948

Year	Ilmenite				Rutile			
	Production, short tons	Shipments			Production, short tons	Shipments		
		Gross weight, short tons	TiO_2 content, short tons	Value		Gross weight, short tons	TiO_2 content, short tons	Value
1942	77,208	93,397	41,328	\$1,805,823	2,648	2,649	2,466	\$ 410,956
1943	203,551	211,715	94,283	3,738,970	3,987	3,941	3,629	610,879
1944	278,610	280,791	128,095	7,371,279	6,922	6,770	6,312	1,088,112
1945	308,516	308,518	141,852	7,359,170	7,179	6,837	6,414	869,920
1946	282,447	282,708	130,624	4,878,917	7,453	7,514	7,046	996,989
1947	336,533	336,061	157,328	.....	8,562	5,157	.....	.....
1948	383,745	381,508	177,447	5,793,973	7,380	9,907	.....	647,334

TABLE 3. CONSUMPTION OF ILMENITE IN THE UNITED STATES, SHORT TONS

	1947	1948
Pigments.....	473,154	558,448
Alloys and carbide.....	5,972	6,377
Miscellaneous.....	398	?
Total.....	479,524	565,000 (approx)

Imports of ilmenite for 1948 totaled 242,119 tons from the following countries: India, 184,309; Norway, 41,248; Brazil, 8,708. Total imports for 1947 were 301,311 tons. Rutile imports for 1948 totaled 8,771 tons, all from Australia.

World production of titanium minerals is given in Table 4.

TABLE 4. WORLD PRODUCTION OF TITANIUM CONCENTRATES (ILMENITE AND RUTILE), 1940 TO 1946, BY COUNTRIES, METRIC TONS
(Compiled by B. B. Mitchell)

Country	1940	1941	1942	1943	1944	1945	1946
Ilmenite							
Australia:							
New South Wales....	1,538	3,521	3,651	3,815	3,590	^a	^a
Queensland.....		258	937	1,902	3,697	3,000	^a
Brazil (exports).....	12	4,471			3,250	5,000	^a
Canada.....	4,114	11,477	9,100	62,992	30,820	12,834	1,227
Egypt.....	465	2	691 ^b		9	9	
Federated Malay States (exports).....	2,596	^a	^a	^a	^a	^a	^a
India, British.....	267,376	131,111	49,977	38,396	102,412	^a	^a
Norway.....	51,700	61,086	60,713	66,191	63,975	^a	^a
Portugal.....	899	798		121		301	^a
Senegal ^c	7,082	1,000	4,840	730		3,200	^a
Spain.....		71	85	178	548	26	^a
United States.....	18,750	21,135	70,042	184,657	252,749	279,880	256,230
Total ilmenite.....	354,532	236,930	200,036	358,982	461,050	^a	^a
Rutile							
Australia:							
New South Wales....	1,641	3,549	4,496	4,828	4,597	^a	^a
Queensland.....		267	1,007	1,655	4,246	4,000	^a
South Australia.....	2	^d					^a
Brazil (exports).....	499	2,369	4,615	4,557	1,564	160	^a
Cameroun, French (exports).....	503	1,399	2,153	2,750	2,902	1,046	^a
India.....	934	1,891	2,295	2,396	1,672	^a	^a
Norway.....	156	172	77	116	85	^a	^a
United States.....	2,620	2,839	2,402	3,617	6,279	6,513	6,761
Total rutile.....	6,355	12,486	17,045	19,919	21,345	^a	^a

^a Data not available. Estimates for individual countries included in world totals shown.

^b Includes 26 tons of garnet-ilmenite.

^c Approximately 20 per cent of ilmenite concentrates is zircon.

^d Less than 1 ton.

Utilization. By far the most important use for titanium minerals to date has been in making pigments. The high index of refraction of titanium dioxide and its compounds, plus its white color and high reflectivity or brightness, results in remarkable opacity or hiding power that is made use of in pigments for paints, paper, rubber, enamels, plastics, coated fabrics, leather, and many products.

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The U.S. Bureau of Mines reports that since 1939 titanium pigments have been used in greater quantity than any other white pigment. Separate production figures for titanium pigments are not published, but *Chemical Engineering*²³ estimates the 1947 production at over 300,000 tons or about 40 per cent of the total production of all white pigments. They estimated the distribution by use as shown in Table 5.

TABLE 5. ESTIMATED UNITED STATES CONSUMPTION OF TiO_2 PIGMENTS

Industry	Per Cent
Paint, varnish, and lacquer.....	75
Paper.....	10
Rubber.....	2
Floor coverings.....	2
Leather.....	2
Textiles.....	1.5
Welding-rod coating.....	1.5
Other.....	6
Total.....	100

The earliest forms of pigments were not considered suitable for outside paints due to their tendency to chalk badly, but this condition no longer exists because the chalking tendency has been reduced or eliminated in improved pigments and because it is now recognized that a moderate amount of chalking is desirable.

Titanium pigments are now made in the following types:

Titanium dioxide 95 per cent or more TiO_2 , rutile and anatase types

Titanium-barium a mixture of TiO_2 and barium sulfate (blanc fixe)

Titanium-calcium a mixture of TiO_2 and calcium sulfate

Titanium-magnesium a mixture of TiO_2 and magnesium silicate

Lead titanate PbTiO_3

Of the straight TiO_2 pigments the greatest production is of the anatase type, but the rutile type with its higher index of refraction has considerably greater hiding power.

Titanium pigments are made almost wholly from ilmenite. The ground ore is digested in concentrated sulfuric acid; the iron is reduced to the ferrous state with scrap iron; the solution is diluted and boiled to hydrolyze the titanium sulfate to the insoluble oxide; the TiO_2 is separated from the ferrous sulfate by filtration, washed, dried, and reground. The original titanium-barium pigment, consisting of about 75 per cent BaSO_4 and 25 per cent TiO_2 , was made by precipitation of TiO_2 in a suspension of blanc fixe. The titanium-calcium pigment, about 70 per cent CaSO_4 and 30 per cent TiO_2 , was made in a similar way using a calcium sulfate suspension. Later these pigments were made by dry blending in mixers, with little or no loss in desirable properties.

The titanites have displayed unusual and desirable properties in the manufacture of high dielectric ceramic bodies.^{11,27}

It is now possible to make pure, transparent, colorless boules of monocrystalline titania, TiO_2 , of the rutile type by fusion of the powder in an oxyhydrogen torch^{15a} in the same way that synthetic ruby and sapphire are made. This colorless

titania, with its very high index of refraction and dispersion six times that of the diamond, may be cut into blazing gems of far greater fire and brilliance than the diamond. Gems are now being produced commercially, the first wholly new gem in modern history, and its successful acceptance seems assured. The boules, as first made, are strong semiconductors of electricity, opaque and black in color. By heating in an oxidizing atmosphere the color changes successively from black to deep blue, light blue, green, to colorless with a slight yellow tone, and perfect transparency. It also changes to a high dielectric. These changes are reversible upon heating in a reducing atmosphere at least four times without materially affecting the properties.

Distribution of titanium mineral consumption by uses is shown in Table 6.

TABLE 6 CONSUMPTION OF ILMENITE AND RUTILE IN THE UNITED STATES, 1945 TO 1946, BY PRODUCTS, SHORT TONS

Product	Ilmenite		Rutile	
	Gross weight	Estimated TiO ₂ content	Gross weight	Estimated TiO ₂ content
1945				
Pigments (manufactured TiO ₂)*.....	371,691	183,195		
Welding-rod coatings*.....	115	62	7,813	7,344
Alloys and carbide.....	8,611	3,976	1,923	1,750
Ceramics.....			34	30
Miscellaneous†.....	761	347	21	20
Total consumption.....	381,178	187,580	9,791	9,144
1946				
Pigments (manufactured TiO ₂)*.....	399,042	200,352		
Welding-rod coatings*.....	105	57	5,990	5,600
Alloys and carbide.....	4,685	2,025	1,035	966
Ceramics.....			75	72
Miscellaneous*.....	451	229	34	32
Total consumption.....	404,283	202,663	7,134	6,670

* "Pigments" include all manufactured titanium dioxide, consumption of which in welding-rod coatings was 2,258 tons in 1945 and 938 tons in 1946.

† Consists of ilmenite used as a steel flux and rutile used in lamp-electrode coatings and as a steel deoxidizer.

Metallic Titanium. A new use for titanium minerals which may, within a few years, overshadow that for making pigments is for making metallic titanium. This is by no means a new metal, but it has only attracted widespread attention within the last few years when work by several research laboratories and pilot plants has developed processes by which eventually it may be available in large quantities at a reasonable price. Its great potential value results from a most favorable weight-strength ratio. On a volume basis it is twice as strong as iron and six times as strong as aluminum. Its weight is about two-thirds that of iron

and only about 60 per cent greater than aluminum. When pure it is ductile and malleable; it may be alloyed with other metals and it has high resistance to corrosion. These properties make it very desirable for many uses, particularly in airplanes. Several pilot plants are now producing small commercial quantities that are sold at about \$5 per pound. The metallurgy is complex and difficult, but optimists predict a possible future price as low as 50 cents per pound. However, this price cannot be attained by any of the processes now known. (See Refs. 4, 5, 6, 8a, 12, 13, 14, 22, and 28.)

TITANITE

Composition. Titanite, sometimes called sphene, is a silicate of calcium and titanium, CaTiSiO_5 or $\text{CaO} \cdot \text{TiO}_2 \cdot \text{SiO}_2$: CaO, 28.57 per cent; TiO_2 , 40.82 per cent; SiO_2 , 30.61 per cent. It may contain some iron and manganese.

General Description. Titanite commonly occurs as brown, yellow, or green wedge-shaped, tabular, or prismatic monoclinic crystals, or in compact masses, or in disseminated grains, with resinous to vitreous luster.

Physical Properties. Hardness, 5 to 5.5. Specific gravity, 3.4 to 3.6. Melting point, 3 in scale of fusibility. Index of refraction, 1.900 to 2.034. Color, brown to black, yellow, green, or red. Streak, white. Luster, resinous or vitreous to adamantine. Cleavage, good prismatic, fair pyramidal. Fracture, conchoidal. Transparency, transparent to opaque. Tenacity, brittle. Soluble in sulfuric acid.

Occurrence. Titanite occurs as an accessory mineral in many igneous rocks. It is associated commonly with amphiboles, pyroxenes, zircon, and iron minerals. Specimens have been found in many areas, particularly Grenville, Quebec; Renfrew County, Ontario; Franklin Furnace, N.J.; Magnet Cove, Ark.; Norway; and Switzerland.

Utilization. Transparent crystals in pleasing shades have been cut as a gem stone. The high index of refraction ensures brilliance. To date the mineral has had no industrial significance due to the small tonnage in which it has been found, the relatively low TiO_2 content, and the difficulties of breaking down a silicate to liberate its titanium content.

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TOPAZ

Composition. Topaz is a silicate of aluminum containing fluorine and hydroxyl, $\text{Al}_2\text{SiO}_4(\text{F}\cdot\text{OH})_2$. The percentages of fluorine and hydroxyl vary greatly.

General Description. Topaz occurs in well-formed orthorhombic crystals, frequently with one end terminated, the other being a plane produced by its perfect basal cleavage. Since the mineral is hard and heavy it may be found in rounded water-worn pebbles in placer deposits.

Physical Properties. *Hardness*, 8. *Specific gravity*, 3.4 to 3.6. *Melting point*, high. *Color*, colorless, yellow, blue, gray, green, pink. *Streak*, white. *Luster*, vitreous. *Index of refraction*, 1.619 to 1.627. *Cleavage*, perfect, basal. *Fracture*, conchoidal to uneven. *Transparency*, transparent to opaque. *Tenacity*, brittle.

Occurrence. Topaz is a characteristic pneumatolytic mineral found in place and in cavities in pegmatites and in highly acid igneous rocks, such as granites and rhyolites. It is often found as an associate of apatite, beryl, mica, and tin and tungsten ores. Gem material has been found in the United States in the Thomas Mountains of Utah, near Nathrop, Colo., and in the pegmatite areas of New England and San Diego County, Calif. It has been found in many foreign countries.

Utilization. Clear crystals and pebbles of attractive color have been used as a gem stone for centuries. The pale yellow, sherry-brown, and blue varieties have been most in demand. The yellow topaz of Brazil may be altered to a beautiful pink tint by the application of heat.

Massive Topaz in South Carolina. All ideas concerning the occurrence and available tonnage of topaz were altered by the discovery of large deposits of this mineral in Chesterfield County, S.C. It was found first as a placer deposit near the Brewer Mine. This mine had been operated intermittently as a source of gold for a hundred years. The topaz occurs in rounded masses, with a waxy luster where the surface is smooth. In general appearance it resembles a gray siliceous chert. Color displays considerable variation from gray to black with areas of white and brown. Banding and mottling color effects are present.

Hardness varies from 7 to 8 and specific gravity from 3.40 to 3.47. Subsequent search discovered the mineral in place, and thousands of tons were blocked out for mining. Chemical analysis shows variation depending upon the location of the sample and the care with which it was prepared. An early analysis reported by Pardee, Glass, and Stevens is as follows:⁶

	<i>Per Cent</i>
Silica (SiO_2).....	33.00
Alumina (Al_2O_3).....	56.76
Iron oxide (Fe_2O_3).....	Trace
Water ($\text{H}_2\text{O}-$).....	0.04
Water ($\text{H}_2\text{O}+$).....	2.67
Fluorine (F_2).....	13.23
	<hr/> 105.70
Less $\text{O} = \text{F}$	5.57
	<hr/> 100.13

Burgess² reports the changes that take place in the material after calcination which causes conversion of the mineral to mullite:

	Before calcination	After calcination
Silica (SiO_2).....	40.20	28.90
Alumina (Al_2O_3).....	50.28	71.06
Iron oxide (Fe_2O_3).....	0.92	0.22
Fluorine (F_2).....	12.74	0.15
	<hr/> 104.14	<hr/> 100.33
Specific gravity.....	3.49	2.91

Calcination removes most of the fluorine and this takes most of the iron and part of the silica with it, probably as volatile fluorides. All the fluorine can be driven off at 1340°C . The PCE (pyrometric cone equivalent) of the calcined material was found to be cone 40 equivalent to 1885°C . Upon calcination the topaz converts to mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$). Burgess states that calcined topaz approaches mullite closer than Indian kyanite or any domestic product. This material has been found useful in the manufacture of superduty refractories. The tonnage available was particularly valuable during the war, when imports of kyanite from India were obtainable with difficulty.

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TOURMALINE

Composition. Tourmaline is a complex silicate of boron and aluminum in whose structure many elements may be introduced. Its composition therefore exhibits great variety. The formula may be said to correspond to $WX_3B_3Al_3(AlSi_2O_9)_3(O \cdot OH \cdot F)_4$, where W represents sodium and calcium and X represents aluminum, ferric iron, lithium, or magnesium.

General Description. Tourmaline is found frequently in well-developed hexagonal crystals, sometimes in radiating crystalline aggregates or masses. The crystals exhibit characteristically a spherical triangle in cross section. Color may show great variation in a single crystal, which may be red at one end and green at the other, or the colors may be arranged zonally so that the interior is red and the exterior green.

Physical Properties. *Hardness*, 7 to 7.5. *Specific gravity*, 2.19 to 3.2. *Melting point*, 1062 to 1152°C. *Color*, red, green-blue, yellow, brown, or black. The black variety is known as "schorl"; it is sometimes found in tonnage. *Streak*, white. *Luster*, vitreous to resinous. *Index of refraction*, 1.641 to 1.687. *Cleavage*, poor. *Fracture*, conchoidal to irregular. *Transparency*, transparent to opaque. *Tenacity*, brittle. The crystals are strongly pyroelectric and assume an electric charge after heating, becoming positive on one end and negative on the other on cooling. Sections of transparent material polarize light. It displays the property of pleochroism, that is, different colors may appear, depending upon the side of the crystal from which the material is viewed. A knowledge of this property is valuable at times in deciding in what position a gem should be cut from a crystal to produce the most desirable color effect.

Occurrence. Tourmaline occurs frequently in pegmatites. The best gem material has been recovered from this source. It is also found in metamorphic rocks such as schists, gneisses, and crystalline limestones. It is also found as small rounded grains in sandstones and in loose sands. Fine colored crystals of gem quality have been found near Paris and Auburn, Maine; Mesa Grande, Pala, and elsewhere in San Diego County, Calif.; in Russia, Brazil, Burma, Ceylon, and Madagascar. Schorl, the high-iron, black variety, is a common associate of high-temperature quartz and is commonly encountered in gold mining.

Utilization. Clear, flawless, and attractively colored tourmalines have been used as gem stones for centuries. Their value was higher 75 years ago before appreciable production was obtained from Brazil and other sources. Massive rubellite, a pink tourmaline, has been used for intricate carving by the Chinese artists in this craft. The black massive material has been employed as a grinding medium for the fine grinding of gold ores in Ontario. A saving of a few cents a ton was claimed for this material in preference to the flint pebbles previously employed. The use of tourmaline oscillator plates for radio control has been investigated carefully and research in this activity continues. The piezoelectric properties of tourmaline are such that it possesses promise in this field. Oscillator plates cut from tourmaline crystals were introduced in 1931.

An important but small tonnage use for high-grade tourmaline was developed during the Second World War. This was for use in piezoelectric gages for the measurement of blast pressures in air and under water. Tourmaline is one of the few natural minerals that respond piezoelectrically to hydrostatic pressure. Clean crystals free from cracks and strains are needed, but color and transparency are unimportant. In spite of the relative abundance of black tourmaline, suitable material has been very scarce. It has been sold at prices ranging from \$15 per pound up to a reported \$1,000 per pound, but the lower figure is probably a fair price under normal conditions. The principal war sources were Madagascar and Brazil and imports totaled something over 5,000 lb during this period.³ All the artificial crystals so far developed are unsuitable because they are water soluble and mechanically weak, but efforts are being made to grow artificial tourmaline crystals.²

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TREMOLITE

Composition. Tremolite is calcium magnesium silicate, $\text{CaMg}_3(\text{SiO}_3)_4$: CaO , 13.4 per cent; MgO , 29.0 per cent; SiO_2 , 57.6 per cent.

General Description. Tremolite usually occurs as white or gray, bladed, prismatic crystals in fibrous or asbestiform aggregates or as compact granular or columnar masses. *Hexagonite* is a pinkish or lavender variety (color due to a small amount of manganese) occurring principally associated with tremolite and talc in St. Lawrence County, N.Y.

Physical Properties. *Hardness*, 5 to 6. *Specific gravity*, 2.9 to 3.1. *Melting point*, 1269 to 1273°C. *Index of refraction*, 1.609 to 1.635. *Color*, white, gray, greenish, or yellowish. *Streak*, white. *Luster*, vitreous to silky. *Cleavage*, perfect prismatic at angles of 56 and 124 deg. *Transparency*, transparent to opaque. *Tenacity*, brittle, slightly flexible.

Occurrence. Tremolite is a contact metamorphic mineral and usually occurs in crystalline limestones, dolomites, and schists. When it forms the major constituent of a schist, the term "tremolite schist" is applied. It alters to talc; the fibrous talcs of St. Lawrence County, N.Y., grade into tremolite. Other localities are the talc districts of California; Easton, Pa.; Maryland; Renfrew and Lanark counties, Ontario; Alaska; Italy; and St. Gothard district, Switzerland.

Utilization. The largest commercial uses for tremolite are in ceramics and in paint, though it is not sold as tremolite but as fibrous talc. Most of the ceramic grade of "talc" from St. Lawrence County, N.Y., is chiefly tremolite, and the ceramic talcs of California are high in tremolite. The close association of tremolite with talc in New York State is such that very large tonnages of the resulting talc-tremolite mixture have been sold and used as talc.

The fibrous nature of tremolite from some deposits has permitted its use in a very limited way as asbestos. However, the fiber is too brittle for most purposes for which asbestos is used, except for chemical filter fiber. For this use it is preferred to chrysotile asbestos because it is more resistant to acids. Tremolite filter fiber has been mined in Maryland, California, and elsewhere (see Asbestos). Italian asbestos has been mined in quantity for this use.

The nephrite variety of jade is a tough, compact, fine-grained variety of tremolite or actinolite.

The ceramic behavior* of tremolite has been investigated in part by Amberg.¹ Research has shown that talc and tremolite may be separated by flotation.

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TRIPOLI

Definition. Tripoli is a form of silica (SiO_2) derived either from the decomposition or alteration of chert or as a residual product from the decomposition of a highly siliceous limestone. It has been suggested that the Missouri type of tripoli is perhaps a direct deposition of colloidal silica followed by leaching of alkaline salts.

Tripoli is often confused, both in the trade and in the literature, with tripolite, which is another name for diatomaceous earth (see page 185). Often these two terms are incorrectly used interchangeably, but in reality they apply to two entirely separate and distinct substances, each with its own characteristic physical and chemical properties. The original tripolite from the island of Tripoli in northern Africa was diatomaceous earth, while the term "tripoli" was first applied to a material found near Seneca, Mo., which somewhat resembled diatomaceous earth by visual inspection, but contained no diatoms, was of entirely different origin, and had different physical and chemical properties. The presence or absence of diatoms, when examined under a high-power microscope, is the absolutely definite test. However, the unusually low apparent specific gravity of diatomaceous earth (as low as 0.45 for dried blocks) is commonly a clue to its identity, but some of the Missouri type of tripoli also has a low apparent specific gravity. Chemical analyses always show that diatomaceous earth has a high content of combined water (5 to 10 per cent or more), while tripoli has little or none. This is illustrated in Table 1.

In the trade tripoli is known as "soft" silica or "amorphous" silica to distinguish it from the quartz or sand type.

General Description. There are two types of tripoli, and they differ so widely in physical properties that they require separate treatment. These will be termed the Missouri-Oklahoma type and the Illinois-Tennessee type, although deposits of each type are known in other states.

The Missouri-Oklahoma type of tripoli usually occurs in layers in compact bedded deposits. It is an extremely porous, lightweight material, varying from loosely coherent to fairly compact. It is so soft that it can easily be cut with the fingernail, and even the most coherent varieties can be crumbled to a powder between the fingers, due to its porous structure. It is very rarely pure white and usually ranges from cream colored to yellow, brown, rose, and red, the coloring matter being chiefly iron oxide. Although it may easily be crumbled to a powder, the ultimate individual grains (usually 0.01 mm or finer) are so hard that they will scratch steel. The grains are doubly refracting and are probably chalcedony.

TABLE 1. TYPICAL ANALYSES OF TRIPOLI AND DIATOMACEOUS EARTH

	Tripoli			Diatomaceous earth
	Seneca, Mo.	Illinois	East Tennessee, Georgia	Lompoc, Calif.
	1	2	3	4
Silica (SiO_2).....	98.28	99.40	93-98	88.78
Alumina (Al_2O_3).....	0.17	0.22	1.0-1.4	2.68
Iron oxide (Fe_2O_3).....	0.53	0.14	0.22-0.16	Trace
Lime (CaO).....	Trace	.....	Trace-0.30	1.61
Potash (K_2O).....	0.17			
Soda (Na_2O).....	0.27			
Magnesia (MgO}).....	.....	.....	.....	1.30
Titanium oxide (TiO_2).....	Trace-0.20	0.10
Water (H_2O).....	0.50	0.25	0.3-0.7	5.54
Total.....	99.92	100.01	100.01

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Tripoli of this type, when dry, is very absorbent. It is stated that a block 4 in. square will absorb one-third its weight of water (complete saturation) in 5 min. This moisture will dry at ordinary room temperature and humidity in about 3 days. In small pieces the fracture is very uneven, but in large blocks in the quarry a tendency toward concentric or conchoidal fracture is often found. Some beds in the Missouri-Oklahoma district are of sufficiently compact material that large, fairly strong blocks may be removed. These were formerly worked up into filters.

Physical Properties. *Seneca, Mo., Type of Materials.*³ Free quartz, less than 0.5 per cent. Oil absorption, average, 50.71 to 53.14 per cent. Specific gravity, variously reported as 2.15 to 2.62. Weight per cubic foot, crude 35 lb., ground 55 lb. Fusion point, 3225 to 3300°F. Refractive index, 1.54.

Illinois-Tennessee Type. This type of tripoli varies in structure from pulverulent and entirely noncoherent in the Tennessee phase to hard, compact, and rather dense in the Illinois phase. It is often found in extensive, thick beds more or less mixed with unaltered chert. Its color is usually a very pure white, but certain portions of some deposits are stained by iron oxide to cream, yellow, brown, and rose. The noncoherent or Tennessee phase is very uniform in grain size, and the average diameter of particle is about 0.002 mm or 2 microns (2μ). The Illinois phase is so hard and compact that much of it cannot be crushed

between the fingers, although it can be cut with difficulty with a knife. It grades by imperceptible degrees into unaltered chert. The hard massive tripoli is heavy (specific gravity 2.2 to 2.5) and but slightly absorbent, compared with the Missouri material.

Geographical Distribution and Methods of Production. *Missouri-Oklahoma Type.* The only deposits of this type which have been worked extensively are in Missouri and Oklahoma near the border between the two states. The center of this district is Seneca, Newton County, Mo. The best Oklahoma deposits are near Gate in Ottawa County. The principal deposits are distributed over an area of less than 100 square miles, but other scattered deposits are found beyond this area. The beds of tripoli lie horizontal and usually have less than 12 ft of overburden. This overburden, consisting of loose dirt, gravel, and decomposed tripoli, averages about 5½ ft in thickness. The beds themselves range from 2 to 12 or 14 ft in thickness. While the beds are apparently extensive, often chert seams and boulders occur in such abundance that grinding would be uneconomical.

A weight of 1 short ton per cu yd in place is used in estimating ore reserves. The color of the tripoli in place varies from a light cream color with few iron-stained seams to dark-cream and rose shades with much iron staining. Aside from the seams, the whiteness is proportional to the fineness of grain. This is because the coarse rock is more porous, allowing more iron-bearing water to seep in or circulate through. In addition to color, chert seams and nodules must be watched for; these must be picked out and discarded, for they are very difficult to grind.

In opening a deposit, the overburden is first removed by hand or by small steam shovels. The tripoli is then drilled by hand to the bottom of the bed in rows of holes parallel to the working face and shot down with black powder. The broken material is sledged to small sizes, sorted to remove wastes, and separated into three grades based on color: rose, cream, and "white" (really a light cream). From the quarries the ore is hauled to the mills in quarry cars or light motor trucks.

Formerly, massive tripoli of uniform quality was quarried by special methods, such as dimension blocks, and worked up into filter stone, disks, and tubes; but these products are now practically obsolete.

The tripoli as quarried is saturated with water (20 to 35 per cent), which must be removed before grinding. Originally air drying in sheds was practiced; then artificial drying was tried but it was found that the absorptive properties were lowered by this method. By present methods the crude tripoli is racked in drying sheds and air-dried for 3 to 6 months, depending on weather and season. Then it is coarse-crushed (to about ¼ in.), and drying is completed in artificial driers under carefully controlled heat. Primary grinding is done in a hammer mill, followed by pebble mills in closed circuit with vibrating screens and air separators. From quarry to final product great care is taken to select the tripoli into two or three standard grades based on color: rose, cream, and sometimes white. The lighter colored types sometimes are more difficult to mill than the darker shades, due to static electricity, and special screening techniques are needed.

The products of the Barnsdall Tripoli Corp. of Seneca, Mo., are as follows: "Once Ground," or minus 65-mesh product, 87 per cent of which is -200 mesh; "Double Ground," or minus 110-mesh product, 96 per cent of which is -200 mesh; "Air Float," or all -250 mesh; and "Special Air Float" or all -300 mesh or finer. These grades are made in rose and cream colors.

Deposits of the Missouri type are known in a few other localities, such as 12 miles south of Rome and near Dalton, Ga. Sporadic production has come from a few of these deposits, but they have not proved successful competitors of the type material.

Illinois-Tennessee Type. Deposits of tripoli of this general type are apparently more widespread than those of the Missouri-Oklahoma type. Deposits of this type have been worked or are known to exist in Illinois, Tennessee, Georgia, Alabama, Mississippi, and Nevada.

The Illinois district, which has been the largest producer in the past, includes portions of Alexander and Union counties in the southern part of the state and centers about Tamms, Elco, Jonesboro, and Wolf Lake. The tripoli here occurs associated with unaltered chert in large deposits, usually under so heavy an overburden that underground mining methods must be used. The tripoli is nearly pure white and is much harder and higher in specific gravity than the Missouri tripoli. The purest material is soft and very fine grained, but average pieces are not easily cut with a knife. It does not break easily and its fracture is very rough and uneven. Hard lumps of partially decomposed chert are common.

The silica is mined by room-and-pillar methods, using black powder as the explosive. As mined the tripoli averages about 25 per cent combined and absorbed moisture, and it feels cold and clammy to the touch.

In the Illinois district milling is commonly done wet. After crushing to $\frac{1}{4}$ or $\frac{1}{2}$ in. the silica is fine-ground in tube mills with flint linings and flint pebbles. Sizing of the finished product was formerly done by settling in long shallow tanks with steam drying coils in the bottom. The coarsest particles settled nearest the tank intake and the finest at the opposite end. After a period of quiet settling the water was drawn off and the product dried by the steam coils. By an improved method now used the pebble mills are placed in closed circuit with bowl classifiers, by which means accurately sized products may be made. The classified product is thickened and dried and packed for shipment.

Dry grinding is also done in the Illinois field as well as in Tennessee and elsewhere. Methods in most plants have been similar. The crude silica is dried in a rotary drier and ground in a flint-lined Hardinge conical mill or pebble mill in closed circuit with an air separator. At a plant formerly operated near Hot Springs, Ark., the silica was naturally so fine that no grinding was necessary. After drying, the product was sized in two air separators in series, the first removing a 325-mesh product and the second a 200-mesh product. A similar type of tripoli was formerly produced at Black Fox, near Cleveland, Tenn.

Operations in Other States. Aside from the areas discussed above tripoli occurs in important deposits in numerous other states. Metcalf³ notes deposits in five other states, and occurrences have been reported in several more. Some production has come from many of these deposits, but most operations have been

short-lived, although several have been in production within the past few years, for example, at Rogers, Benton County, Ark., where a white silica of the Illinois type is produced by wet milling. A narrow belt of deposits extends northeast and southwest from Wayne County, Tenn., into Lauderdale County, Ala., and along Bear Creek in Colbert County, Ala., into Tishomingo County, Miss. This belt contains the well-known deposits in the Waynesboro-Collinwood district in Tennessee, the deposits near Riverton and Tredegar, Ala., and that near Iuka, Miss. All these deposits are of the Illinois type but tend to occur as fine-grained, unconsolidated aggregates. For example, that at Tredegar is reported to run 50 per cent — 300 mesh as mined. Tripoli deposits have been reported in nine counties in northwestern Georgia. Production has come in recent years from a deposit near Barstow, San Bernardino County, Calif. Deposits have been reported near Goldfield and Cuprite, Nev., and a small production has come from Texas as a by-product of a fuller's earth operation.

Production and Consumption. All United States government figures of production for tripoli also include rottenstone, but since the latter production has always been small the annual totals given cannot be very misleading. The largest recorded domestic production was 43,257 tons in 1916, valued at \$215,216. In the past 20 years the greatest production was in 1929, when it reached 38,011 tons valued at \$545,658. The minimum from 1929 to 1940 was 14,775 tons in 1932, valued at \$232,700 and the average range in this period was from 20,000 to 34,000 tons. Recent production statistics as published by the U.S. Bureau of Mines are given in Tables 2 and 3.

TABLE 2. TRIPOLI (INCLUDING PENNSYLVANIA ROTTENSTONE) SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1942 TO 1946

Year	Illinois		Missouri and Pennsylvania*		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1942	12,575	\$203,390	4,961	\$ 69,038	17,536	\$272,428
1943	10,203	168,758	4,709	75,607	14,912	244,365
1944	12,031	205,732	6,394	96,131	18,425	301,863
1945	11,144	184,189	7,103	122,640	18,247	306,829
1946	15,631	321,600	13,324	227,499	28,955	549,099

* Includes Arkansas in 1942 to 1944 and Oklahoma in 1943. Missouri and Pennsylvania figures in 1945 and 1946 were as follows: 1945, Missouri, 6,542 tons, \$114,188; Pennsylvania, 561 tons, \$8,452. 1946, Missouri, 12,180 tons, \$211,244; Pennsylvania, 1,144 tons, \$16,255.

The distribution of production by uses (Table 3) does not give a true picture since it covers the war years of abnormal production and use conditions. For example, in the period 1935 to 1940, concrete admixtures took from 5 to 11 per

TRIPOLI

TABLE 3. TRIPOLI (INCLUDING PENNSYLVANIA ROTTENSTONE) SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1944 TO 1946, BY USES

Use	1944		1945		1946	
	Short tons	Value	Short tons	Value	Short tons	Value
Abrasives.....	13,218	\$210,592	11,113	\$188,262	21,206	\$406,620
Concrete admixture.	316	4,552	1	18		
Filler.....	3,423	66,147	3,969	65,569	4,450	89,721
Oil-well drilling....	*	*				
Other uses†.....	1,468	20,572	3,164	52,980	3,299	52,758
	18,425	\$301,863	18,247	\$306,829	28,955	\$549,099

* Included under Other uses.

† Foundry facing, drilling mud, and unspecified.

cent of the total production; foundry facings took over 16 per cent in 1934; oil-well drilling took nearly 2,000 tons or about 6.5 per cent in 1941.

Note that the statistics in Tables 2 and 3 do not represent the domestic consumption of materials of this general nature, for much silica from other sources is used for many purposes more or less interchangeably with tripoli (see production statistics under Silica, page 427). Also other minerals are used for the same or similar purposes (see Mineral Fillers).

Grades and Prices. Tripoli is sold by reputation, trade preference, trade name, and performance as demonstrated by sample. Prices have exhibited unusual stability and according to the *Engineering and Mining Journal's Metal and Mineral Markets*, prices in 1947 to 1950 were as follows (per ton, burlap bags, paper liners, minimum carload 30 tons, fob Missouri): once ground through 40 mesh, rose and cream colored, \$14.50; double ground through 110 mesh, rose and cream, \$16.00; air floated through 200 mesh, \$26.

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TURQUOISE, VARISCITE

TURQUOISE

Composition. Turquoise is a basic phosphate of copper and aluminum. It crystallizes in the triclinic system and is represented by the formula $H_6[Al(OH)_2]_6Cu(OH)(PO_4)_4$. Copper, to which it owes its color, is a part of the molecular structure of the mineral.

General Description. Turquoise occurs as apparently amorphous (actually cryptocrystalline), bluish, opaque, botryoidal or stalactitic masses in veins, as crusts, as coating and disseminated grains, or as rounded pebbles. Crystals are known although they are of rare occurrence.

Physical Properties. *Hardness*, 6. *Specific gravity*, 2.6 to 2.8. *Melting point*, high. *Index of refraction*, 1.62. *Color*, various shades of blue and green, slowly fades and is destroyed by heat. *Streak*, white. *Luster*, waxy to dull. *Cleavage*, one. *Fracture*, conchoidal. *Transparency*, opaque. *Tenacity*, somewhat brittle.

Occurrence. Turquoise is found in the oxidized outcrops of many copper ore bodies. It is the product of circulating meteoric waters that have leached the necessary constituents from the surrounding rocks and precipitated them in fractures and in shear zones. Gem material of fine quality has been found near Nishapur, in the province of Khorassan, Persia. Excellent material was recovered at a very early date near the copper workings located in the Sinai peninsula, Egypt. Australia and Turkestan are also producers. New Mexico is believed to be the leading producer in the United States, followed by Colorado. The Los Cerillos district in New Mexico is the oldest and most prolific producer. Turquoise has also been produced in small amounts in California, in the Castle Dome mine in Arizona, and in Nevada in the Tonopah and Battle Mountain districts. Turquoise matrix consists of an irregular distribution of the blue mineral in the surrounding rock, which is frequently brown in color due to the presence of iron oxides. Sound material that can be cut and polished may produce a pleasing effect of color and pattern.

Odontolite, or bone turquoise, is confused at times with the true mineral. This variety may be distinguished from turquoise by its greater specific gravity and the remnants of organic structure that may be seen with the microscope. Odontolite is the product of the alteration of ivory or fossil bone occasioned by long burial in the ground and certain chemical reactions producing a blue pigment.

Utilization. Turquoise has been employed as a gem since prehistoric times. It has been the most valued of all the opaque gems. The finest material should be a deep even blue, fine textured, and capable of assuming a good polish. The color should be permanent. Much of the mined material exhibits various shades of green and is valued far below the first-quality blue. Many specimens have shown an unfortunate lack of stability with regard to color, and their value has been decreased by loss of a prime blue shade. Perspiration is reported to have a bad effect on color. Restoration of color by artificial means is frequently accomplished.

VARISCITE

Composition. Variscite is a hydrous aluminum phosphate represented by the formula $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$.

Physical Properties. *Hardness*, 4 to 5. *Specific gravity*, 2.6 to 2.8. *Index of refraction*, 1.57 to 1.58. Due to its resemblance to turquoise it is used at times in its place. It is characteristically apple green in color and is found commonly in nodules. It takes a good polish, but the hardness is not sufficiently high to withstand long abrasive wear.

Production. Considerable production has been attained at Lucin, Utah. Other occurrences have been productive in Tooele and other Utah counties. It is sometimes known as "Utahlite."

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URANIUM MINERALS

Uranium is widely distributed in both igneous and some sedimentary rocks and is a component of many minerals. Most of these are of rare occurrence and the bulk of commercial production has been derived from two: pitchblende and carnotite.

Pitchblende. Pitchblende is the massive form of the mineral uraninite, which has been found in cubic crystals of unusual rarity. Pitchblende is represented by the formula $(\text{UO}_2)\text{UO}_4(\text{H}_2\text{O})_x$. Actually, composition is indefinite. Traces

of a number of rare elements are commonly encountered, and very small amounts of lead and radium are present. *Hardness*, 5.5. *Specific gravity*, 6.5 to 8.0. *Melting point*, infusible. *Index of refraction*, greater than 1.74. *Color*, brown or black. *Streak*, olive green. *Luster*, pitchlike.

Carnotite. Carnotite is generally found in amorphous earthy masses, although small tabular orthorhombic crystals have been described. It is represented by the formula $K_2(UO_2)(VO_4)_2 \cdot 8H_2O$. Radium is present in all uranium minerals in a ratio of 1 Ra/3,000,000 U. *Hardness*, soft. *Specific gravity*, about 4.1. *Melting point*, fusible at 2.5. *Index of refraction*, 1.75 to 1.95. *Color*, canary yellow. *Streak*, yellow. *Luster*, resinous to dull earthy. *Transparency*, transparent to translucent.

Occurrence. Knowledge of the distribution of uranium deposits of commercial importance is based largely on their exploitation as sources of radium. Radium was discovered by Madame Curie in 1898 in pitchblende produced in Joachimsthal, Czechoslovakia. Recognition of the therapeutic value of the element was followed by a widespread search for potential sources. The search for radium thereby became the most valuable agent in disclosing the location of uranium ores. At the same time the growing interest in subatomic chemistry aroused by research associated with radium contributed to the development of what was to become the largest consuming market for uranium: atomic energy.

With the development of the atomic bomb began a worldwide search for uranium that has been intensified since the war. Government buying of ores and the ease of prospecting with the Geiger counter have stimulated prospecting and exploration everywhere on an intensive scale. This has resulted in finding uranium occurrences in many new localities. Most of these deposits prove to be of very small size, but numerous larger ones have been found and in the aggregate give encouragement to the belief that reserves will be adequate to our needs. Gustafson, who has analyzed the future-reserves problem, concludes, "In my judgment the estimates of future uranium supplies that I have seen are far too pessimistic." It is his prediction that "there will be new high-grade uranium producers found, that the old producers will last longer than people think, that there will be significant uranium production from low-grade ores which are not now even considered ore, that we can get large amounts of thorium when and if we need thorium, and there will be enough source material to permit the use of atomic energy to expand considerably and go on for generations."^{6a}

United States. Uranium minerals occur in five types of formations in this country: (1) uranium-bearing carnotite-roscoelite type; (2) uranium-bearing sedimentary rocks (phosphates, shales, etc.); (3) secondary uranium minerals in various types of rocks; (4) primary vein type; and (5) pegmatites (usually small tonnage and of mineralogical interest only). Of these only the carnotite type has so far been of much commercial importance. In this type it is found encrusting fossil carbons and as fossil logs in sandstones. Apparently it has been deposited from meteoric waters and is totally different in genesis from pitchblende, which is closely associated with igneous rocks and hydrothermal solutions. It differs further in its vanadium content. The principal productive area is the Colorado Plateau, which extends over into Utah. The deposits

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individually are small and widely scattered over an area roughly 200 miles in diameter. In 1949 production was coming from nearly 250 separate operations of which about 80 per cent were in Colorado. Carnotite is associated with the vanadium mica, roscoelite. Much of the ore contains 0.1 to 0.3 per cent U_3O_8 and from 0.5 to 2.5 per cent V_2O_5 . There are a few scattered deposits of this type in New Mexico and Arizona. The sedimentary phosphate type occurs in the phosphate districts of Idaho, Montana, and Wyoming.

Foreign Countries. The most important world sources are of the mesothermal vein-type deposits of pitchblende, which yield both radium and uranium. The largest known deposits are those of Czechoslovakia (Bohemia), Canada (Great Bear Lake) and the Belgian Congo. Among the other countries that have known production of uranium minerals are Bulgaria, France, Germany (Schneeberg, Saxony, in Russian area), Norway, Sweden, United Kingdom (Cornwall), Madagascar, and Australia. There is little public information as to Russia's resources, aside from the important deposits that she controls in Czechoslovakia and Saxony.

Czechoslovakia. The pitchblende deposits at Joachimsthal occur in mica schists interbedded with mineralized gneiss. Silver, cobalt, bismuth, and arsenic minerals occur with the pitchblende. The importance of the area as a producer of radium declined after the discovery of richer ores in other districts. The present significance of these deposits is that since 1947 they have been under operation at capacity by the Russian government. The quantity of uranium produced and its disposal are not known.

Belgian Congo. The Shinkolobwe mine is believed to be the largest developed deposit of pitchblende in existence. The discovery was reported in 1915 and development was initiated in 1921. Pod-shaped veins occur in altered graphitic rocks. Accurate estimation of reserve tonnage cannot be made due to the irregularity of the structure. Nickel and cobalt are associated metals. The ore is of sufficiently high grade to permit direct shipment to Belgium for treatment.

Canada. The Eldorado mine on Labine Point, Great Bear Lake, is just south of the Arctic Circle. The discovery was made in 1930, and subsequent development has proved the veins to a depth in excess of 1,000 ft. The veins occur in a shear zone cutting volcanic and sedimentary rocks near a granite. Silver is prominent as a uranium associate and it is recovered as a valuable by-product. The agreement between the Belgian Congo producers and the Eldorado Co., dividing world's market for radium on a 60:40 basis, was reported effective as late as 1940. Possibly this is the best estimate of ore reserve ratios of these producers.

Production. Oxides of uranium are a typical canary yellow in color and readily recognized. They are generally present where uranium-bearing minerals crop out. They have been an aid to the prospector in the search for ores. A more scientific method, the use of the Geiger counter, is now in common use. This instrument registers the radioactive emission common to uranium and thorium minerals. The instrument has been designed in portable form and by an increase in audible clicking or dial reading indicates any abnormal radioactivity. It supplies a qualitative answer only, and determination of the quantitative amount present must be obtained by other means. Since the development of atomic

power from uranium and its military use production figures have become a confidential matter. Shipments of carnotite from mines in the United States for the last years available are shown in Table 1.

A partial report concerning imports is given by Table 2.

The lack of regularity in ore bodies has not been conducive to the application of systematic mining methods. Concentration has been done by hand selection, flotation, and a dry method, applicable to carnotite, consisting of a pulverizing mill and dust collector. The tonnage of reserves for future use is a closely kept secret.

TABLE 1. CARNOTITE ORE AND CONCENTRATES SHIPPED FROM MINES IN THE UNITED STATES, 1932 TO 1941^a

Year	Short tons	Value	Content		
			Uranium, lb	Radium, mg	Vanadium, lb
1932	61	\$ 6,150	3,186	481	3,024
1933	52	3,099	694	256	2,240
1934	254	11,074	6,661	1,007	12,528
1935	1,145	56,223	22,009	3,329	50,776
1936	1,439	73,881	17,961	2,716	52,695
1937	1,708	65,294	20,764	3,141	73,788
1938	4,290	158,779	51,705	7,821	173,859
1939	6,256	174,660	59,269	8,964	206,509
1940 ^b	796	61,800	16,909	2,557 ^c	51,377
1941 ^b	908	70,500 ^d	19,288 ^c	2,916 ^c	50,824

^a Data for 1942 to 1946 not available for publication.

^b Excludes ore sold only for its vanadium value.

^c Estimated on the basis of uranium content in 1940.

^d Estimated on the basis of value in 1940.

Utilization. The first interest in uranium minerals was as a source of radium. This was present in such minute amounts that its extraction became a laborious and expensive operation. Radium was sold at various prices, from \$100,000 to \$25,000 per gram. Radium is the highest priced mineral commodity produced, \$100,000 per gram being equivalent to \$45,360,000 per pound. The accumulation of uranium salts as a by-product of radium production resulted in search for possible markets. Small amounts have been converted to ferroureanum for the production of uranium-bearing steels. The largest chemical consumption has been in the preparation of uranium acetate and nitrate used as an analytical reagent in the determination of sodium and zinc. The glass industry has been a substantial consumer in the production of greenish-yellow fluorescent glass, amber-colored glass, and glass of a specific coefficient of expansion. Small amounts have been used in the photographic industry.

The explosion of the first atomic bomb in New Mexico on July 16, 1945, altered all previous ideas as to the importance of uranium. Ordinary uranium contains

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TABLE 2. URANIUM ORE, CONCENTRATES, AND COMPOUNDS IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1937 TO 1946

Year	Uranium ore and concentrates				Uranium oxide and salts				
	Pounds from			Value	Pounds from				Value
	Belgian Congo	Canada	Total		Belgium	Canada	Other countries ^c	Total	
1937	^b	^b	^b	^b					
1938	^b	^b	^b	^b	160,072	37,846	5,555	203,437	\$ 258,417
1939		5	5	\$ 10	287,752	88,954	2	376,708	520,540
1940	2,400,198		2,400,198	2,110,927	1,333,053	106,271		1,439,324	1,197,786
1941					169,388	70,811		240,199	388,355
1942	525,559	15,748	541,307	806,919	53,090 ^c	334,415		387,505	501,370
1943	^d	^d	^d	^d		377,398		377,398	851,098
1944	^d	^d	^d	^d		211,348		211,348	413,410
1945	^d	^d	^d	^d		4,675	5,750	10,425	11,074
1946	^d	^d	^d	^d		1,080		1,080	2,244
						25		25	41

^a 1937 to 1938: Germany; 1944: United Kingdom.

^b Data not separately recorded.

^c Reported by U.S. Department of Commerce from Belgian Congo, but presumably originated in Belgium if actually a finished compound rather than a concentrate.

^d Data not available for publication.

0.7 per cent uranium 235. Plutonium, a man-made element, is produced by the action of U235 on ordinary uranium, U238. U235 and plutonium are fissionable with enormous energy releases. A military weapon of prime importance appeared, and the proper control of such energy has presented a problem the solution of which has not been found. The industrial utilization of atomic power presents many possibilities of the greatest interest. The production of isotopes and radioactive forms of common elements is providing research tools of unknown potentialities. Government regulation through the Atomic Energy Act of 1946, Public Law 585, controls all activity directly associated with fissionable materials.

Consumption of uranium for nonenergy purposes is presented in Table 3.

TABLE 3. CONSUMPTION OF URANIUM COMPOUNDS FOR NONENERGY PURPOSES IN THE UNITED STATES, 1943 TO 1946, IN POUNDS OF CONTAINED U₃O₈ (Atomic Energy Commission)

Industry	1943	1944	1945	1946
Chemical.....	4,000	6,700	3,800	{ 2,500 360
Photographic.....				
Electrical.....	250	800	1,000	300
Ceramic (including glass).....	7,500	100	150	1,000
Total.....	11,750	7,600	4,950	4,160

The demand for uranium has stimulated the search for deposits, and it is possible that discoveries of other minerals such as torbernite, autunite, and others may alter the supply of raw material.

Prices. In the paper given by John K. Gustafson, director of the division of raw materials, Atomic Energy Commission, he states that there is no standard price for uranium.* The government is attempting to encourage exploration and production by means of the following program:

1. The government guarantees a 10-year minimum price of \$3.50 per pound of contained U_3O_8 for small amounts of domestic refined uranium and \$3.50 per pound of recoverable U_3O_8 , less refining charges for small lots of ore or mechanical concentrates, assaying at least 10 per cent U_3O_8 .

2. A bonus of \$10,000 is guaranteed for the discovery of a new deposit and production of the first 20 tons of uranium ore or mechanically produced concentrates assaying 20 per cent or more U_3O_8 .

3. Prices are guaranteed for a 3-year period for low-grade carnotite and roscoelite-type uranium-vanadium ores of the Colorado Plateau area and operation of two treating plants in that area.

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VERMICULITE

Definition. The term "vermiculite" is given to a group of hydrous micas, usually alteration products of phlogopite or biotite micas, characterized by the ability, when heated above 150°C, to expand at right angles to the cleavage to a volume 6 to 20 times (average 16) that of the unexpanded mineral. Within the group many subvarieties are listed, the best known being the specifically named vermiculite and jefferisite. Other variety names, such as culsageeite, kerrite, maconite, and dudleyite, are usually minor local varieties of the type material and have little significance.

Vermiculite was first described in 1824 from a deposit near Worcester, Mass. Jefferisite was discovered in 1851 from a deposit near West Chester, Pa., and named as a new mineral in 1861. Commercial production started in a small way about 1915 in Colorado. It was identified in a number of other localities, but it was not until the large-tonnage deposits of Libbey, Mont., were found in 1916 that it was recognized that this mineral could be produced in quantity sufficient to allow its extraordinary properties to be utilized by industry.

Physical Properties. Except for its ability to expand, physical properties in general are similar to those of other micas. *Hardness*, 1.5. *Specific gravity*, 2.3 to 2.8 (after expansion, about 0.9). *Color*, brown and dark green to black. (After expansion, gold, bronze, silver, brown, black, or nearly white.) *Streak*, white. *Tenacity*, elastic to pliable. *Melting point*, 1320 to 1350°C. *Exfoliation*, rapid and extensive between 150 and 650 to 800°C.

Composition. Vermiculite is essentially a hydrous magnesium mica containing varying amounts of iron. Attempts to assign a definite, theoretical mineralogical formula for it are unsuccessful because of its highly variable composition. Analyses of typical material, as assembled by Laschinger,¹¹ are given in Table 1.

Occurrence. Vermiculite is found with basic rocks such as pyroxenites, dunites, or their alteration product, serpentine. This geologic occurrence is similar to that of phlogopite, the magnesium mica, whose occurrence in Canada and elsewhere has been described under Mica. The geologic origin of vermiculite

TABLE 1. ANALYSES OF VERMICULITES

	Theoretical vermiculite	Libby, Mont.	Palabora, South Africa	West Chester, Pa.
SiO ₂	36.71	41.0	39.37	34.20
TiO ₂.....	.....	.....	1.25	
Al ₂ O ₃	14.15	18.0	12.08	16.58
Fe ₂ O ₃	4.43	7.0	5.45	7.41
FeO.....	.....	.....	1.17	1.13
MnO.....	.....	.....	0.30	
MgO.....	24.62	21.0	23.37	20.41
CaO.....	.....	1.0	1.46	
Na ₂ O.....	.....	1.0	0.80	
K ₂ O.....	.....	1.0	2.46	
H ₂ O and 105°C.....	20.09	11.0	11.20	21.14

is by no means clear. It is believed commonly that it is the alteration product of large masses of phlogopite or biotite by hydrothermal waters. The solvent action of these waters has removed most of the alkalis and hydrated the remaining material, producing a mica possessing the peculiar properties of vermiculite.

Geographically, vermiculite is found in widely separated areas, as is shown by production in the United States. In 1946 seven states reported commercial output: Montana, Wyoming, Colorado, Nevada, North Carolina, South Carolina, and Texas. The location of the raw material has had a controlling effect on the mechanical development of the industry. Most of the deposits are located in areas remote from densely populated markets. Since the expanded material is very light it is difficult to pack sufficient tonnage in a car to make a minimum carload. Therefore, the tendency has been to construct expanding plants in central locations in important market areas and to ship raw material from the mines. This procedure is followed on imported material as well as domestic.

Although the most important commercial production has come from the United States, deposits are known in numerous foreign countries, some of which are beginning to be important producers either for export or for local consumption.

United States. Montana. The largest known deposit of vermiculite is in Lincoln County, Mont., 7 miles northeast of Libbey. It was discovered during the First World War in a search for vanadium. The exfoliation and expansion of the mineral encountered in drifts were observed when heated with a lamp flame. The deposits are in the form of a dike about 100 ft wide by 2 miles long and of unknown depth. It occurs in a coarse-grained pyroxenite, ranging in mineral composition from pyroxene to biotite or its alteration product, vermiculite. There is evidence of widespread hydrothermal action. The vermiculite constitutes from 30 to 84 per cent of the pyroxenite rock. These deposits to date have been by far the largest producers anywhere, and the industry as it exists today was founded by the original producing company.

North Carolina has recently been the second largest producing state, and it was the first in the East to maintain sustained commercial production, beginning

in 1933. The most important deposits so far have been at Ellijay, Macon County, and Swannanoa, Buncombe County, but deposits are reported elsewhere in these counties as well as in Avery, Clay, Jackson, Transylvania, and Yancey counties.

Other producing states in recent years have been *South Carolina* (at Tigerville, Travellers Rest, and other points in the Piedmont area); *Wyoming* (near Encampment; also deposits near Wheatland, south of Glenrock, and in the Sweetwater Uplift west of Casper); *Colorado* (deposit near Canon City and plant at Colorado Springs; also deposits near Westcliffe, Fremont County, near Rosita, and at several other localities); *Texas* (near Burnet); and *Nevada* (near Silver Peak and elsewhere). Other states containing deposits of possible commercial interest or that have been small producers in the past are Arizona, California, Georgia, Utah, Pennsylvania, Maryland, Massachusetts, and Oregon.

South Africa is rapidly becoming a producer of increasing importance in the world's markets. The most important deposit is located at Palabora in northeastern Transvaal. The deposit, which covers about three-quarters of a square mile, has been proved in places to a depth of 80 ft. The total tonnage present is

TABLE 2. SCREENED AND CLEANED VERMICULITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1935 TO 1939 (AVERAGE) AND 1940 TO 1948

Year	Short tons	Value
1935-1939 (average)	18,486	\$180,297
1940	22,299	137,698
1941	23,438	125,444
1942	57,848	319,931
1943	46,645	471,595
1944	54,116	541,744
1945	64,808	648,077
1946	86,390	867,973
1947	131,385	1,338,572
1948	138,635	1,387,233

believed to be very large. The vermiculite is associated with pyroxenite and serpentine, from which it must be separated. It has been reported that production in 1945 was 1,411 tons; this rose in 1947 to 15,775 tons.* A much higher output is believed possible by mechanization of mining operations. The raw material is in part expanded for local use and in part exported to the United States, England, and other countries. That imported into this country is expanded in a plant at Newark, N.J.

Russia is known to have important deposits of vermiculite in the dunite and pyroxenite areas of the Ural Mountains, famous for their production of platinum. Some of these deposits have

been developed and the expanded products used for loose-fill insulation and insulating brick.

Australia has vermiculite deposits in the Bulong and Kalgoorlie areas of Western Australia that have been developed for home markets.

Japan. Vermiculite deposits of unknown importance have been reported at several places in Japan.

Brazil. It is reported that there is a large deposit of vermiculite at Ponte Nova in the state of Minas Geraes. In mid-1948 it was stated that they were exporting about 900 tons per month to the United States and that production was being expanded to take care of the demand.

* *Eng. Mining J., Metal and Mineral Markets*, Aug. 12, 1948.

Production and Consumption. United States production of cleaned and screened, but not expanded, vermiculite in recent years is shown in Table 2.

Assuming a loss in exfoliation of 5 per cent and an average value of \$75 per ton for the expanded product, the total United States production in 1946 as sold in expanded form was worth about \$6,155,000. Statistics of imports and exports are not available, but it is known that imports of unexpanded vermiculite from South Africa are large.

Mining and Milling. Large, flat-lying, bedded deposits amenable to mechanization have been worked by shovel. Narrow veins require underground mining methods at higher production costs.

Few or no vermiculite deposits are pure enough over large areas to permit of use without beneficiation. Mine-run vermiculite usually contains such gangue minerals as quartz, feldspar, biotite, and country rock. These are removed as far as possible by hand sorting. Many and various methods for the further removal of impurities have been tried, but the usual methods involve drying, coarse crushing in hammer mills, screening, and sometimes air separation. In general, separation from impurities depends largely upon the difference in particle shape between the thin flat vermiculite plates and the more or less equidimensional grains of impurities. After beneficiation the material is screened into fairly close size fractions because close sizing results in more efficient and uniform exfoliation.

Exfoliation methods are described in some detail by Goldstein,⁵ who gives references to more extended descriptions. To obtain the best type of product with maximum toughness of grains and a minimum of milling losses the time and temperature in the hot zone of the furnace must be so regulated that total free water will not be reduced below 5 or 6 per cent. Complete removal of all free and combined water occurs at about 1000°C and the resulting product is very brittle; heating, therefore, is usually not carried above 650 to 850°C.^{6,8,10,19} A number of types of kilns or furnaces have been used:

1. Rotary kiln, similar to cement kiln but smaller and much shorter
2. Vertical kiln with inclined baffles permitting material to fall by gravity through heating zone
3. Inclined furnace with shaking plate

The weight of expanded material (South African) for various sizes is given in Table 3, according to Laschinger.¹¹

TABLE 3. EXPANDED VERMICULITE

Size	Lb/ft	Cu ft/short ton	Cu ft yield/1 ton / raw mineral
1 in.-1/2 in.	3.3	606	548
1/2 in.-1/4 in.	3.8	526	476
1/4 in.-5 mesh	4.4	455	411
5-10 mesh	5.1	392	355
10-18 mesh	6.0	333	302
18-36 mesh	8.5	235	213

The property of expansion has been explained by at least two theories. The most generally accepted one is that the expansion is caused by the pressure of steam generated by heating the water of composition. This process is similar to that involved in the "popping" of perlite, and the product is somewhat similar except in one detail. The expansion is in one direction only—at 90 deg to the cleavage plane. The flake may increase from 10 to 30 times its original thickness. The second theory is that much of the expansion is due to warping of individual laminae because of unequal strains set up by steam pressure. This theory is used to account for the fact that expansion takes place even with very slow heating—slow enough to allow the steam to escape quietly.

In addition to the increase in volume and the development of the minute voids responsible for its insulating value, the vermiculite is altered by oxidation of its iron content. By controlled furnacing some vermiculites may be produced in gold, silver, or bronze colors suitable for decorative use. Too high an iron content makes a nearly black color, while a low iron content makes a creamy-white product.

Marketing and Shipping. Sales to the ultimate consumer are always of the expanded product; but unexpanded, screened, and cleaned vermiculite is sold and shipped in bulk or in bags to expanding plants all over the country and abroad. There are now probably over 50 expanding plants in this country alone. Expanded vermiculite is sold either in bulk or in bags, usually holding 4 cu ft each.

The unexpanded product is sold on a per ton basis, fob producing plant. The expanded material is sold at a price per cubic foot.

Prices. In 1950, screened and cleaned vermiculite sold for \$12 per short ton, fob mines, Montana. African vermiculite sold for \$28 to \$30 per ton fob Atlantic ports. Expanded vermiculite prices varied with location of markets and type of use. Prices for home insulation may range from \$60 to \$100 per ton, packed in 25-lb bags.

Utilization. The principal tonnage uses for vermiculite depend upon the presence of innumerable minute air cells, which make it a good insulator against heat, cold, and sound and which give it a very low apparent specific gravity. Unlike cork and other organic lightweight insulating materials it will not rot or mold and is not attacked by vermin, and it has fair mechanical strength. The largest single use is probably in the house-insulating field, but uses in lightweight concrete and plasters and in industrial insulations of all types are very important.

Since many vermiculites that expand satisfactorily also decrepitate to a fine grain size and do not yield much of the coarser, blocky granules needed for the largest uses and since these fine sizes show a higher apparent specific gravity, the disposal of fines is an important problem with some producers. Table 4, prepared for the Tennessee Valley Authority and published in the U.S. Bureau of Mines' "Minerals Yearbook" for 1936 (page 1070), is outdated but is valuable for its information on distribution of uses by grain size. A large number of new uses have been developed since Table 4 was prepared, many of them patented. Goldstein⁵ gives a good recent summary of uses and the properties on which the uses depend. Among the uses not noted above are insulators for hot-water tanks, deep-freeze units, safes, and fireless cookers; lightweight wall plasters and

TABLE 4. USES OF VERMICULITE

$\frac{1}{4}$ In.-20 Mesh	40-120 Mesh
House insulation	Linoleum
Home refrigerators	Shingles
Auto mufflers	Cornice boards
Acoustic plaster	Dielectric switchboards
Safe and vault linings	120-200 Mesh
Pipe covering	Grease lubricant
Boiler lagging	Bakelite products
Smelter ladles	Tire and rubber goods
Refractory brick	200-270 Mesh
Insulation cement	Wallpaper printing
20-40 Mesh	Outdoor advertising paints
Auto insulation	Building up viscosity in oil
Airplane insulation	Fireproof cartons for films
Refrigerator-car insulation	270 Mesh
Passenger-car insulation	Extender for gold and
Wallboard	bronze printing ink and
Water coolers	for paint
Annealing steel	
Fire extinguishers	
Filters	
Cold storage	

roof decks; inert layers on top of kettles of molten metal to prevent oxidation; and in horticulture, as a porous, sterile soil for starting seedlings (may be treated with nutrients).

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VESUVIANITE

Composition. Vesuvianite, frequently called idocrase, is a complex silicate of calcium and aluminum. It is represented by the formula $\text{Ca}_{10}\text{Al}_4(\text{Mg,Fe})_2\text{Si}_9\text{O}_{34}(\text{OH})_4$. Substitution of many other elements in the structure is possible.

General Description. The mineral commonly occurs in short tetragonal prisms. Striated columnar masses and brown prismatic forms are characteristic. A massive compact green variety resembling jade is known as "californite."

Physical Properties. *Hardness*, 6.5. *Specific gravity*, 3.3 to 3.5. *Melting point*, fuses at 3 in the scale of fusibility to a greenish or brownish glass. *Color*, brown, green, yellow, blue, black. *Streak*, white. *Luster*, vitreous, greasy, or resinous. *Index of refraction*, 1.705 to 1.721. *Cleavage*, indistinct prismatic and basal. *Fracture*, uneven. *Transparency*, transparent to opaque. *Tenacity*, brittle.

Occurrence. Vesuvianite is a typical contact metamorphic mineral and is found usually in crystalline limestones. It is associated with tourmaline, garnet, wollastonite, and other metamorphic minerals. It was found originally in the rocks of Mount Vesuvius and in the altered dolomites of ancient Monte Somma. It has been found in many localities in Switzerland, Italy, Mexico, and Russia. It occurs in the United States at Rumford Falls and Auburn, Maine; Franklin, N.J.; and in Siskiyou, Fresno, and Tulare counties, Calif. The compact, massive variety of vesuvianite, first found in Siskiyou County, is known as *californite*. It varies from olive to grass green in color and takes a fine polish. Extensive outcrops and large loose masses have been found. It was believed to be jade,

which it closely resembles, when first discovered. Analyses of this material are given in Table 1.¹

TABLE 1. ANALYSES OF VESUVIANITE

	Siskiyou County, Calif.	Fresno County, Calif.
SiO ₂	35.85	36.55
Al ₂ O ₃	18.35	18.89
CaO.....	33.51	35.97
Fe ₂ O ₃	1.67	0.74
FeO.....	0.39	0.74
MgO.....	5.43	2.33
MnO.....	0.05	
TiO ₂	0.10	
P ₂ O ₅	0.02	
CO ₂.....	.....	0.91
F.....	.....	0.13
H ₂ O below 100°C.....	0.29	0.58
H ₂ O above 100°C.....	4.18	3.42
	99.84	100.26

A vesuvianite found with the zinc ores of Franklin, N.J., has attracted attention due to the remarkably high percentage of beryllium that has been introduced in the structure of the crystal. Analysis of picked crystals is given in Table 2.²

TABLE 2. BERYLLIUM VESUVIANITE*

SiO ₂	34.25
CaO.....	33.15
BeO.....	9.20
MgO.....	3.17
MnO.....	4.84
ZnO.....	4.86
Al ₂ O ₃	9.70
H ₂ O.....	1.31
FeO.....	Trace
	100.48

* Ores from Franklin, N.J.

Utilization. Clear and attractively colored specimens of vesuvianite have been cut and polished as a gem stone. It has been substituted for jade in carvings and beads. The quantity consumed is small. The beryllium-rich variety has been considered as a source for this desirable lightweight metal. Commercial production has not been reported.

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WAVELLITE

Composition. Wavellite is a hydrous aluminum phosphate. Its formula is generally given as $\text{Al}_3(\text{OH})_3(\text{PO}_4)_2 \cdot 5\text{H}_2\text{O}$ or as $\text{Al}_6(\text{OH})_6(\text{PO}_4)_4 \cdot 9\text{H}_2\text{O}$. Water of crystallization is variable. On the basis of the second formula the composition is Al_2O_3 , 28.0 per cent; P_2O_5 , 35.2 per cent; H_2O , 26.8 per cent. Fluorine is reported in some varieties.

General Description. Wavellite is a fairly soft mineral, usually found in crystalline crusts or in radiating or globular masses made up of concentric layers with a radial fibrous structure. Sometimes stalactitic.

Physical Properties. *Hardness*, 3.5 to 4. *Specific gravity*, 2.3 to 2.4. *Color*, white, green, yellow, or brown. *Streak*, white. *Luster*, vitreous. *Index of refraction*, 1.525 to 1.552. *Cleavage*, prismatic, well developed. *Fracture*, conchoidal to uneven. *Transparency*, translucent. *Tenacity*, brittle. Easily recognized by its radiating globular structure. The presence of aluminum may be confirmed by moistening with cobalt nitrate and igniting. This produces a blue coloration.

Occurrence. Wavellite is considered a rare mineral of secondary origin. It is found frequently in the linings of cavities and in nodules in clays. No large deposits are known. It is probable that substantial tonnages occur, but they are dissipated to such an extent in certain geologic horizons that commercial extraction is not feasible. As far as is known the only commercial recovery of record was obtained during a few years after 1900, 4 miles west of Mount Holly Springs, Pa. The wavellite occurs here as residual nodules in a deposit of clay. It is scattered through it irregularly, and attempts to arrive at an estimate of probable tonnage have not been successful. During 1905 some 400 tons were produced. The deposit was worked as an open cut to a depth of 30 ft, and then a shaft was sunk to the bottom of the deposit, about 52 ft, and continued through 16 ft of manganese ore. In 1902 a plant was built at Moores Mill near Mount Holly Springs to reduce the ore to phosphorus. The Pennsylvania State Geologic Survey reports that wavellite was mined at one time at Whitehouse Station in East Whiteland Township, Chester County, Pa. The amount of material produced and its disposal are not known.

An interesting occurrence of wavellite and amblygonite was reported years ago in the western end of Juniata County, Pa. It was found at various points within 12 miles of Reed's Gap in a so-called "black belt" at the foot of a low ridge of Oriskany sandstone. The mineral was found in nodules of varying composition, reported to contain as much as 30 per cent phosphorus pentoxide. Positive confirmation of the identity of amblygonite has not been made. Attempts were made to mine this material and drifts were driven into the sandstone to facilitate the extraction of the phosphate. The date and success of the operation are unknown. It was abandoned and apparently the material was of too low grade to permit economic recovery.

Utilization. At Mount Holly Springs the wavellite was manufactured into phosphorus. The process was secret but in general is believed to have been as

follows. The wavellite was mixed with phosphorite calcium phosphate obtained from South Carolina, roasted, mixed with silica and charcoal, and reduced in an electric furnace. The phosphorus fumes were condensed under water as crude, yellow phosphorus, which required further treatment. It was used in the manufacture of matches. Some of the material obtained in other areas is believed to have been ground and used as a fertilizer.

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WOLLASTONITE

Composition. Wollastonite is calcium metasilicate with the formula CaSiO_3 : CaO, 48.25 per cent; SiO_2 , 51.75 per cent.

General Description. Wollastonite is usually found in elongated tabular crystals or in fibrous or granular compact masses.

Physical Properties. *Hardness*, 4 to 5. *Specific gravity*, 2.8 to 2.9. *Color*, white to gray. *Luster*, vitreous. *Transparency*, transparent to translucent. *Cleavage*, fibrous. *Tenacity*, brittle. *Melting point*, 1512°C . *Index of refraction*, 1.616 to 1.631.

Occurrence. Wollastonite is commonly found as a metamorphic mineral associated with garnet in metamorphosed limestones.

Extensive deposits occur near Willsboro, Essex County, N.Y. Here a band of contact metamorphosed rocks, $\frac{1}{4}$ mile wide by about 6 miles long, contains wide, more or less parallel veins or bands of wollastonite, partly interbedded with and partly intergrown with the rothoffite and colophonite varieties of andradite garnet, together with thin layers of green diopside-hedenbergite (var. salite). The impurities that constitute 10 to 20 per cent of the rock mass may be readily removed by magnetic separation or by gravity methods. The ore is extremely friable and thus is very easily crushed and ground. In the finest ground fractions the grains retain their fibrous structure. Production to date has been by benching in open quarries.

Analyses of commercial wollastonite are given in the table on page 584.

Large deposits of wollastonite occur near Code Siding, Kern County, Calif. The exposure has been traced for about 7,500 ft. The first commercial production of wollastonite came from this deposit in 1933.

WOLLASTONITE

ANALYSES OF WOLLASTONITE

	Essex County, N.Y.*	Kern County, Calif.†	Theoretical
SiO ₂	50.90	47.12	51.75
CaO.....	46.82	41.72	48.25
MgO.....	0.85	2.72	
Fe ₂ O ₃	0.64	1.60	
Al ₂ O ₃	0.78		
MnO ₂	0.20		
TiO ₂	0.08		
CuO.....	0.05		
Na ₂ O.....	0.08	Trace	
	100.40	93.16	100.00

* From producer.

† From J. D. Thorndyke, Mineral Wool from Wollastonite, *Mining and Met.*, Vol. 17, No. 351, pp. 133-136, March, 1936.

Production. Wollastonite has been produced in California since 1933 for making mineral wool and, on a small scale, in New York since about 1943 for miscellaneous uses, but no production statistics have been published. Most of the sales of the New York material have been of the crude, hand-selected rock or of small lots of purified and ground material produced in a pilot plant.

Utilization. The largest use for wollastonite so far developed has been that of the California material for making white mineral wool.¹⁰ For this use it has the advantage of uniform composition and little loss on melting, since a ton of raw material produces nearly a ton of finished product.

Extensive research has been done on the New York wollastonite. Many tentative uses have been developed, for several of which patent applications have been filed. Its purity, uniformity, inertness, very pure white color and brilliance, ease of grinding to very fine particle size, and the fibrous particle shape suggest its usefulness as a filler in paint, paper, rubber, etc.

An established use is as an ingredient in arc-welding rod coatings and flux-shielding compounds (U.S. Patent 2269167). For the patented use the New York wollastonite with its accompanying garnet and diopside is used without separation.

In ceramics research has indicated that it can be used in whitewares as a partial substitute for feldspar and in floor and wall tile.

Acid-treated wollastonite has been introduced in Canada as a substitute for clay in filling and coating paper. It is claimed that this filler can be sold in the clay price range and that it has many advantages over clay, including better color and brightness, higher retention, greater smoothness, higher opacity, and other points of superiority.

A chemically precipitated artificial wollastonite with the trade name of Silene has been introduced by the Columbia Chemical Division of the Pittsburgh Plate Glass Co. as a white, rubber-reinforcing pigment with other industrial possibilities in the filler and pigment field.

The by-product garnet from the New York material may be sold as a low-priced abrasive garnet for stone grinding and polishing and other uses—fields that have been closed to abrasive garnet in the past due to high cost.

Considerable work has been done on the use of calcium silicate as a soil conditioner and plant-fertilizing material in place of limestone.^{4,6,8,9} Its content of silicic acid seems to assist assimilation by the plant of other plant foods such as the phosphates.

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ZIRCON AND ZIRCONIUM MINERALS

Only two minerals are commercial sources of zirconium: *zircon* and *baddeleyite*, also known as *brazilite*. The trade name *zircite* is applied to a commercial ore of zirconia, composed of a mixture of baddeleyite or brazilite, zircon, and a supposed new, unnamed silicate of zirconium.

ZIRCON

Composition. Zircon is zirconium silicate, ZrSiO_4 or $\text{ZrO}_2 \cdot \text{SiO}_2$: ZrO_2 , 66.99 per cent; SiO_2 , 33.01 per cent; or Zr, 49.51 per cent; Si, 15.57 per cent; and O_2 , 34.92 per cent. It often contains a small amount of iron.

ZIRCON AND ZIRCONIUM MINERALS

General Description. Zircon is usually found in small brownish or grayish square prisms capped by simple pyramids; also as rounded or angular lumps, and as rounded grains in sands and gravels. Reddish and brownish varieties when transparent are sometimes called *hyacinth* or *jacinth*; the colorless or smoky varieties, *jargon*.

Physical Properties. *Hardness*, 7.5. *Specific gravity*, 4.4 to 4.8. *Melting point*, 2550°C. *Index of refraction*, 1.952. *Color*, commonly brown or grayish; also colorless, reddish, green, and yellow. *Streak*, white. *Luster*, adamantine. *Cleavage*, imperfect, parallel to both pyramid and prism. *Transparency*, opaque to transparent. *Tenacity*, brittle. Very infusible and inert. *Coefficient of expansion*, less than that of fused quartz. *Dielectric strength*, very high even at a bright-red heat.

BADDELEYITE

Composition. Baddeleyite or brazilite is an oxide of zirconium, theoretically ZrO_2 : Zr, 73.9 per cent; O₂, 26.1 per cent. It usually contains small amounts of iron, silica, alumina, and sometimes titanium. Zircite contains from 70 to 94 per cent ZrO_2 .

General Description. Baddeleyite is a hard, heavy mineral with a nearly perfect basal cleavage, varying in color from colorless to black. Baddeleyite usually refers to the variety in distinct crystals, while the term "brazilite" is applied to the fibrous, botryoidal or columnar forms. The commercial ore is usually found in pebbles in stream beds or in irregular masses in clays.

Physical Properties. *Hardness*, 6.5. *Specific gravity*, 5.5 to 6.025. *Melting point*, 2500 to 2950°C (latter figure for pure ZrO_2 ; impurities lower melting point greatly). *Boiling point* (pure fused ZrO_2), 4300°C. *Specific heat* (amorphous), 0.1075. *Index of refraction*, 2.13 to 2.20. *Color*, black, brown, yellow to colorless. *Streak*, white. *Luster*, greasy to vitreous to submetallic. *Cleavage*, nearly perfect basal. *Transparency*, opaque to translucent. *Tenacity*, tough when massive. *Coefficient of expansion* (pure fused ZrO_2 , about the same as fused quartz), 0.00000084. *Electrical resistance* (pure fused ZrO_2 ; 1200°C), 1.2×10^8 ohms per cm.

Occurrence. Zircon is a common mineral found in small amounts in granites, syenites, and some schists. As far as is known, zircon has been mined only once from the original host rock. This was in Henderson County, N.C. The zircon was found in unaltered crystals in a kaolinized and decomposed pegmatitic dike. The decomposition had penetrated to a depth of some 40 ft. The zircon crystals were separated from the earthy kaolin by hand labor until an accumulation of commercial interest was attained. Production was started in 1888, became dormant, and was resumed in 1902. The total output was small, and in 1905 the largest production on record was obtained—8,000 lb. The destruction of zirconium-bearing rocks by natural geologic processes has liberated the zirconium minerals, which have concentrated in placers along streams or marine beaches.

Brazil. Zircon is present in the beach sands of Bahia, Espirito Santo, and Rio de Janeiro. It is recovered as a by-product in the treatment of monazite sands. A far more important mineral is baddeleyite. This is found in the Caldas region in the states of Minas Geraes and Sao Paulo. Alluvial pebbles are found

along small streams and in the talus at the foot of ridges. This material is of high grade and carries 90 per cent or better zirconium oxide. Zircite, a lower grade material than the true baddeleyite, carries from 75 to 85 per cent zirconium oxide. A few isolated boulders weighing up to 30 tons have been reported. Mining methods are rather primitive, and the nature of the deposit and the size of the market have not favored mechanization or a large capital investment.

India. Zircon is produced as a by-product of the sands of Travancore, which are collected and concentrated primarily as a source of monazite and ilmenite. The marine sands renew themselves periodically due to the action of storms, which rework the area and produce another concentration of the heavy minerals.

Australia. Australia is the most important supplier of zircon concentrates. Black sands, the result of wave action, are found along the eastern coast of New South Wales for about 400 miles from Sidney to the Queensland border. Rutile and ilmenite are common associates of zircon. Prompt action upon the discovery of a commercial concentration is necessary, since the deposit may be dissipated by later wave action.

United States. Zircon production in the United States is now restricted to Florida. The mineral is found with ilmenite and rutile in the dune sands near South Jacksonville. Production in 1946 was at a record level, not made public but known to be in excess of the former record of 3,646 tons in 1927.

Mining and Preparation. As noted, the deposits do not lend themselves to systematic mining. The common practice is to move beach sands with dredge, dragline, bulldozer, or shovel. Gravity concentration—frequently tables (Humphrey spirals in Florida)—is employed to eliminate the quartz and produce a heavy mineral aggregation. The dried concentrate is subjected to magnetic separation of varying intensity to remove magnetite, ilmenite, garnet, and monazite. Electrostatic treatment is then applied to the residual material to produce a rutile and zircon fraction. The zircon is separated further into varying grades and sizes and sold as technical, ceramic, or electrical zircon.

Price. In 1950 zircon ore was quoted at \$40 to \$45 per ton, cif Atlantic seaboard, minimum 65 per cent ZrO_2 .

Utilization. The total consumption of domestic and foreign zircon was reported to be a record of 20,555 tons in 1946. According to the U.S. Bureau of Mines the estimated distribution of usage was as follows: refractories, 28 per cent; vitreous enamels, 25 per cent; electrical and chemical porcelains, 19 per cent; metal and alloys, 16 per cent; pottery glazes, 10 per cent; and miscellaneous, 2 per cent. To satisfy these markets imports in recent years were substantial as is shown in the table on page 588.

As a refractory zircon has a high melting point with a pyrometric cone equivalent of almost 42. It has low thermal expansion and good resistance to abrasion and to the action of certain metals and slags. It is a valuable opacifier in the manufacture of glass.

Zirconium metal is an excellent "getter" at elevated temperatures, having the ability to absorb up to 40 per cent oxygen and 20 per cent nitrogen. The powdered metal is used in the manufacture of radio transmitting tubes, permitting the production of a high-vacuum tube with clear glass. It is also utilized with

ZIRCON AND ZIRCONIUM MINERALS

ZIRCONIUM CONCENTRATE IMPORTED FOR CONSUMPTION IN THE UNITED STATES,
1942 TO 1946 BY COUNTRIES, SHORT TONS^a

Year	Zircon				Baddeleyite from Brazil	Accessory titanium minerals ^d	Total zirconium concentrates ^b	
	From Aus- tralia	From Brazil	Other ^c	Total			Short tons	Value
1942	11,145	...	196	11,341	15,283	7,282	33,906	\$816,364
1943	11,472	110	...	11,582	8,821	8,009	28,412	697,704
1944	11,317	"	...	11,317	2,332 ^e	10,384	24,033	576,299
1945	17,138	"	6	17,144	792 ^e	8,534	26,470	554,400
1946	11,535	"	4	11,539	2,431 ^e	2,844	16,814	453,458

^a Totals and country breakdown by the U.S. Department of Commerce. Mineral breakdown by Bureau of Mines.

^b Classified as "ore" by U.S. Department of Commerce.

^c From India, 1942; French West Africa (Senegal), 1945; Canada, 1946.

^d Rutile and ilmenite content of mixed zirconium-titanium concentrates imported from Australia.

^e Any zircon imports from Brazil, 1944 to 1946, included with baddeleyite.

titanium in the manufacture of pyrophoric alloys for use in cigarette lighters. A number of new alloys are coming on the market.

In recent years there has been a considerable increase in interest in metallic zirconium^{4,9} and its alloys. Ductile zirconium has been made on a laboratory scale,^{4a} and it seems possible that this metal may become of increasing importance.

Transparent zircons have been used as gem stones from prehistoric times. The high index of refraction of the stone ensures brilliance. The blue varieties from Siam and Indochina have been popular, and the colorless material has been sold extensively. Its brilliance and color play approach those of the diamond, but the material is too soft, comparatively, for permanent wear.

Hafnium. Hafnium, a rare element, has been produced by treatment of zircon containing this metal. The process of recovery is slow and expensive and total production has been small. The superiority of hafnium compounds as refractories, particularly the nitride, has created interest in this material. Possibility of commercial production in useful tonnage appears remote.

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APPENDIX

Scale of Hardness

The hardness of a mineral is usually determined by the relative ease with which it is scratched or abraded. The hardness is referred to Mohs' scale, which is given below in order of increasing hardness:

- | | |
|-------------|-------------|
| 1. Talc | 6. Feldspar |
| 2. Gypsum | 7. Quartz |
| 3. Calcite | 8. Topaz |
| 4. Fluorite | 9. Corundum |
| 5. Apatite | 10. Diamond |

In each case the standard hardness refers to that of the pure crystalline material. Sometimes graphite is used in place of talc for 1 and beryl in place of topaz for 8. This scale is not absolute, but relative only. Thus, there is a far greater difference between diamond (10) and corundum (9) than between fluorite (4) and calcite (3). The fingernail will usually scratch a mineral up to 2.5 in the scale, a copper coin up to 3.0, and a good knife blade up to 5.5. Ordinary window glass is about 5.5.

Hardness is determined by scratching (not merely marking) the unknown by successive minerals in the scale until one is found that will scratch, and in turn may be scratched by, the unknown.

Mohs' scale is inadequate both because the methods of testing are very crude and because the intervals between the steps in the scale are not uniform. Numerous attempts have been made to remedy these deficiencies. Ridgway, Ballard,

TABLE 1. HARDNESS OF MINERAL AND MANUFACTURED PRODUCTS

Mohs' scale	Ridgway-Ballard-Bailey extension to Mohs' scale	Knoop-Peters-Emerson diamond indentation value
6. Orthoclase 7. Quartz 8. Topaz	6. Orthoclase or periclase 7. Pure fused silica (fused quartz) 8. Quartz; stellite 9. Topaz 10. Garnet 11. Fused zirconia; tantalum 12. Carbide	Fused quartz 475
9. Sapphire	Fused alumina; tungsten carbide 13. Silicon carbide 14. Boron carbide	Fused alumina 1635 Silicon carbide 2000 Boron carbide (molded) 2230
10. Diamond	15. Diamond	

and Bailey² proposed an extension of Mohs' scale to include artificially prepared substances. Knoop, Peters, and Emerson¹ devised a diamond indentation method of measuring hardness that gives reproducible results on a wide variety of materials. It has the merit of giving definite numerical values over a wide range up to the hardness of the diamond.

Table 1 shows a comparison between these various hardness values for some of the harder materials.

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Scale of Fusibility

The melting points of minerals usually cannot be determined with great accuracy because they seldom occur unmixed with greater or lesser amounts of impurities. Often the presence of small amounts of impurities considerably alters the melting point. There also may be a considerable difference in temperature between the softening point and the point at which the mineral becomes

TABLE 2. SCALE OF FUSIBILITY*

Class	Mineral and true melting point	Behavior under heat
Easily fusible	Stibnite (530°C) or sulfur (107–113°C) Chalcopyrite or galena (777°C) Almandite garnet (1315°C) or stilbite	Large fragments fuse easily in yellow gas flame Small fragments fuse to a globule in the yellow flame Small fragments fuse with difficulty to globule in oxidizing flame
Fusible with difficulty	Actinolite (1322–1346°C) or barite Orthoclase feldspar (1185–1270°C) or sphalerite (1099°C) Bronzite (1345–1350°C) or calamine	Coarse edges are rounded in oxidizing flame Needlelike fragments become globular in oxidizing flame Needlelike fragments become rounded on the point in hot flame
Infusible	Quartz (1456–1480°C) or topaz	Infusible in ordinary blow pipe

* True melting point, where known, is given in parentheses after each mineral.

fluid. Some minerals do not melt under ordinary conditions, but sublime (pass off as a gas) or decrepitate (fly apart).

Mineralogists, however, roughly determine the melting point of a mineral by comparing its behavior under heat with that of a set of minerals known as the Scale of Fusibility. This scale (Table 2) is not at all accurate, as will be noted by comparing the true melting points given for each mineral with the scale.

Segger Cones

In the ceramic industries, kiln temperatures are commonly measured by the use of pyrometric cones or Seger cones. These are slender triangular prisms, about 3 in. high with a $\frac{3}{4}$ -in. base, made of standard combinations of mineral materials in proportions such that they will melt at definite temperatures. A series of cones is used, with melting points ranging from 590 to 1910°C, varying by 20 to 30°C intervals.

The cones are placed upright in a clay base in the kiln. As the temperature

TABLE 3. MELTING POINTS OF SEGER CONES

Cone No.	Temperature		Cone No.	Temperature		Cone No.	Temperature	
	°C	°F		°C	°F		°C	°F
022	590	1094	01	1130	2066	18	1490	2714
021	620	1148	1	1150	2102	19	1510	2750
020	650	1202	2	1170	2138	20	1530	2786
019	680	1256	3	1190	2174	26	1650	3002
018	710	1310	4	1210	2210	27	1670	3038
017	740	1364	5	1230	2246	28	1690	3074
016	770	1418	6	1250	2282	29	1710	3110
015	800	1472	7	1270	2318	30	1730	3146
012½	875	1607	8	1290	2354	31	1740	3182
010	950	1742	9	1310	2390	32	1770	3218
09	970	1778	10	1330	2426	33	1790	3254
08	990	1814	11	1350	2462	34	1810	3290
07	1010	1850	12	1370	2498	35	1830	3326
06	1030	1886	13	1390	2534	36	1850	3362
05	1050	1922	14	1410	2570	37	1870	3398
04	1070	1958	15	1430	2606	38	1890	3434
03	1090	1994	16	1450	2642	39	1910	3470
02	1110	2030	17	1470	2678			

risers, the cones, in order, first soften, then begin to bend over until the tips touch the base, and then fuse down completely. The temperature is sometimes taken from the cone whose tip touches the base and sometimes from the one whose tip just begins to bend. The melting point of the cones depends both upon their composition and upon the rate of heating. Strictly accurate results cannot be obtained with pyrometric cones, but they are much used and of considerable value in the ceramic industries.

Various slightly differing sets of cones are in use in different countries. The cones listed in Table 3 are in common use in the United States. The temperatures given are those at which the cones begin to melt.

The fusion point of ceramic materials, as determined by Seger cones, is expressed as the pyrometric cone equivalent or PCE value.

TABLE 4. INTERNATIONAL ATOMIC WEIGHTS, 1947 REVISION

Element	Sym- bol	Weight	Atomic No.	Valence	Melting point, °C	Boiling point, °C
Actinium.....	Ac	(227)	89			
Alabamine.....	Ab	(221)	85	1, 3, 5, 7		
Aluminum.....	Al	26.97	13	3	659.7	1800
Antimony.....	Sb	121.76	51	3, 5	630.5	1380
Argon.....	A	39.944	18	0	-189.2	-185.7
Arsenic.....	As	74.91	33	3, 5	.....	615 (subl.)
Barium.....	Ba	137.36	56	2	850	1140
Beryllium.....	Be	9.02	4	2	1350	1500
Bismuth.....	Bi	209.00	83	3, 5	271.3	1450
Boron.....	B	10.82	5	3	2300	2550
Bromine.....	Br	79.916	35	1, 3, 5, 7	-7.2	58.78
Cadmium.....	Cd	112.41	48	2	320.9	767
Calcium.....	Ca	40.08	20	2	810	1170
Carbon.....	C	12.01	6	4	> 3500	4200
Cerium.....	Ce	140.13	58	3, 4	640	1400
Cesium.....	Cs	132.91	55	1	28.5	670
Chlorine.....	Cl	35.457	17	1, 3, 5, 7	-101.6	-34.6
Chromium.....	Cr	52.01	24	2, 3, 6	1615	2200
Cobalt.....	Co	58.94	27	2, 3	1480	3000
Columbium.....	Cb	92.91	41	3, 5	2500	3300
Copper.....	Cu	63.54	29	1, 2	1083	2300
Dysprosium.....	Dy	162.46	66	3		
Erbium.....	Er	167.2	68	3		
Europium.....	Eu	152.0	63	2, 3		
Fluorine.....	F	19.0	9	1	-223	-187
Gadolinium.....	Gd	156.9	64	3		
Gallium.....	Ga	69.72	31	2, 3	29.75	> 1600
Germanium.....	Ge	72.60	32	4	958.5	2700
Gold.....	Au	197.2	79	1, 3	1063	2600
Hafnium.....	Hf	178.6	72	4	1700	> 3200
Helium.....	He	4.003	2	0	< -272.2	-268.9
Holmium.....	Ho	164.94	67	3		
Hydrogen.....	H	1.008	1	1	-259.14	-252.7
Illinium.....	Il	(146)	61	(3)		
Indium.....	In	114.76	49	3	155	1450
Iodine.....	I	126.92	53	1, 3, 5, 7	113.5	184.35
Iridium.....	Ir	193.1	77	3, 4	2350	> 4800
Iron.....	Fe	55.85	26	2, 3	1535	3000
Krypton.....	Kr	83.7	36	0	-157	-152.9
Lanthanum.....	La	138.92	57	3	826	1800
Lead.....	Pb	207.21	82	2, 4	327.4	1620
Lithium.....	Li	6.94	3	1	186	> 1220
Lutecium.....	Lu	174.99	71	3		
Magnesium.....	Mg	24.32	12	2	651	1110
Manganese.....	Mn	54.93	25	2, 3, 4, 6, 7	1260	1900
Masurium.....	Ma	.....	43			

APPENDIX

TABLE 4. INTERNATIONAL ATOMIC WEIGHTS, 1947 REVISION. (Continued)

Element	Sym- bol	Weight*	Atomic No.	Valence	Melting point, °C	Boiling point, °C
Mercury.....	Hg	200.61	80	1, 2	-38.87	356.9
Molybdenum.....	Mo	95.95	42	3, 4, 6	2620	3700
Neodymium.....	Nd	144.27	60	3	840	
Neon.....	Ne	20.183	10	0	-248.67	-245.9
Nickel.....	Ni	58.69	28	2, 3	1455	2900
Nitrogen.....	N	14.008	7	3, 5	-209.86	-195.8
Osmium.....	Os	190.2		2, 3, 4, 8	2700	> 5300
Oxygen.....	O	16.000	8	2	-218.4	-183
Palladium.....	Pd	106.7	46	2, 4	1553	2200
Phosphorus.....	P	30.98	15	3, 5	44.1	280
Platinum.....	Pt	195.23	78	2, 4	1773.5	4300
Polonium.....	Po	(210)	84			
Potassium.....	K	39.096	19	1	62.3	760
Praseodymium.....	Pr	140.92	59	3	940	
Protoactinium.....	Pa	231	91			
Radium.....	Ra	226.05	88	2	960	1140
Radon.....	Rn	222	86	0	-110	
Rhenium.....	Re	186.31	75		3000	
Rhodium.....	Rh	102.91	45	3	1985	> 2500
Rubidium.....	Rb	85.48	37	1	38.5	700
Ruthenium.....	Ru	101.7	44	3, 4, 6, 8	2450	> 2700
Samarium.....	Sa	150.43	62	3	> 1300	
Scandium.....	Sc	45.10	21	3	1200	2400
Selenium.....	Se	78.96	34	2, 4, 6	2201	688
Silicon.....	Si	28.06	14	4	1420	2600
Silver.....	Ag	107.88	47	1	960.5	1950
Sodium.....	Na	22.997	11	1	97.5	880
Strontium.....	Sr	87.63	38	2	800	1150
Sulfur.....	S	32.066	16	2, 4, 6	112.8	444.6
Tantalum.....	Ta	180.88	73	5	2996	> 4100
Tellurium.....	Te	127.61	52	2, 4, 6	452	1390
Terbium.....	Tb	159.2	65	3		
Thallium.....	Tl	204.39	81	1, 3	303.5	1650
Thorium.....	Th	232.12	90	4	1845	> 3000
Thulium.....	Tm	169.4	69	3		
Tin.....	Sn	118.70	50	2, 4	231.89	2260
Titanium.....	Ti	47.9	22	3, 4	1800	> 3000
Tungsten.....	W	183.92	74	6	3370	5900
Uranium.....	U	238.07	92	4, 6	< 1150	
Vanadium.....	Va	50.95	23	3, 5	1710	3000
Virginium.....	Vi	(224)	87	1		
Xenon.....	Xe	131.3	54	0	-112	-107
Ytterbium.....	Yb	173.04	70	3	1800	
Yttrium.....	Y	88.92	39	2	1490	2500
Zinc.....	Zn	65.38	30	2	419.47	907
Zirconium.....	Zr	91.22	40	4	1900	> 2900

* Values in parentheses are approximate.

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